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An enhanced fuzzy evidential DEMATEL method with its application to identify critical success factors

Yuzhen Han[1,2] · Yong Deng[1,2]

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Abstract

Due to the frequent occurrence of accidental and destructive disasters, it is essential to improve the performance of emergency systems. Facing the fact that the performance of emergency system depends on various factors and it is not feasible to optimize all these factors simultaneously due to the limitation of resources. A feasible solution is to select and improve some important factors. In this paper, a novel enhanced fuzzy evidential decision-making trial and evaluation laboratory (DEMATEL) method to identifying critical success factors (CSFs) is proposed. In the proposed method, we combine Dempster–Shafer evidence theory and DEMATEL method. Firstly, direct relations between factors are evaluated by multiple domain experts with intuitionistic fuzzy numbers (IFNs). Then, IFNs are transformed to basic probability assignments (BPAs) and can be combined by Dempster combination rule. In addition, the uncertainty and fuzziness of BPAs due to the lack of knowledge are taken into consideration to make final decision. Finally, implementing DEMATEL method, we can figure out cause–effect categories of factors with the DEMATEL method. The cause factors are identified as CSFs. The proposed method can well tackle subjectivity and fuzziness of experts evaluations. Based on the proposed method, the optimization of emergency management can be significantly simplified into optimizing CSFs. Through optimizing these CSFs, the performance of the whole systems can be significantly improved.

Keywords Emergency management · Intuitionistic fuzzy sets · Dempster–Shafer evidence theory · Total uncertainty measure · DEMATEL

1 Introduction

Considering the ubiquitous nature of risk potentiality in our daily life, there is an ever-increasing demand for minimizing losses and adverse effects caused by disruptive events. A useful strategy to protect infrastructure systems is to build an efficient system—emergency system. Emergency management has attracted multitude attention since recent years for the frequent occurrence of accidental events beyond expectations. The effectiveness of an emergency management system greatly matters humans properties and lives. Thus, lots of dedications have been devoted to these years recently. Nevertheless, efforts are still needed to mitigate the negative influences of unexpected accidents for that recent natural disasters still have destructive impacts on contemporary society. For example, a deadly earthquake with a magnitude of 8.0 hit the Wenchuan city in China in 2008, causing above 69,000 confirmed dead. Threaten of Nuclear leakage of Fukushima Nuclear Power Plant lasted for so many years and still existent today. To sum up, the performance of emergency system still needs to be improved.

Emergency management is an interdisciplinary subject applying to highly risk situations which can result in damages. Lots of efforts have been done to optimize it. Zhang et al. (2018c) took the recovery ability of systems into the consideration and designed a resilient network system to defend outer attacks. Guan and Zhuang (2015) applies game theory and expected utility theory models to study the optimal publicCprivate partnerships in disaster preparedness considering the uncertain consequences of the disasters to design

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✉ Yong Deng
dengentropy@uestc.edu.cn; prof.deng@hotmail.com

1 Institute of Fundamental and Frontier Science, University of Electronic Science and Technology of China, Chengdu 610054, China

2 School of Computer and Information Science, Southwest University, No. 2 Tiansheng Road, Beibei District, Chongqing 400715, China

a robust emergency system. Larson (1974) develops computationally efficient algorithms for studying the analytical behavior of a multi-server queuing system with distinguishable servers intending for analyzing problems of vehicle location and response district design in urban emergency services. Azzolin et al. (2018) advanced algorithms for generating synthetic power grids with realistic topological and electrical features, while computationally quantifying how such factors influence system performance probabilistically. Yu proposed a framework by allowing decision-makers to formulate some decision-making frameworks then aggregating them into a group consensus to support the final decision-making (Tolga and Kahraman 1991; Yu and Lai 2011). Xu et al. (2015) constructed a weighted updating model to adjust experts' weights and implements an iterative algorithm to adjust individual preferences thus eliminating conflicts between them. Sheu (2007) designed a hybrid fuzzy clustering method to enhance the performance of emergency management system. Zografos et al. (1998) presented an integrated framework consisting of a data management module, a vehicle monitoring and communications module and a modeling module to improve the effectiveness of emergency response. Zappini et al. (2016) took the advantages of evolutionary metaheuristic for emergency management operations applied to practice. In addition, a large amount of researches have been done in this area (Ilbahar et al. 2018; Kahraman et al. 2018; Tüysüz and Kahraman 2006). Many other researchers also make some explorations in this field and get some good results (Kahraman 2009; Kahraman et al. 2009). 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 et al. (2004) discussed tradeoffs between safety and productivity in critical engineering systems. Rouvroye and van den Bliek (2002) proposed an approach for comparing different safety analysis techniques in emergency management system and described the qualitative and quantitative results from comparison. These methods can improve partial performance instead of systematically improving the overall performance of system (Li and Mahadevan 2016). Other researchers prefer a through upgrade for emergency system (Belassi and Tukel 1996; Kahraman 2014; Somers and Nelson 2001). Based on the intensive literature review, the emergency system has been improved by mainly two ways. Some scholars preferred to improve each component separately responding to their expectations and regard this problem as a multiple-object optimization problem. Since it is always a NP-complete problem, many intelligent evolutionary algorithms have been developed to solve this problem. An improved adaptive particle swarm optimization (DOADAPO) algorithm based on making full use of the advantages of Alpha-stable distribution and dynamic fractional calculus is deeply studied to provide a valuable reference for assigning the gates in hub airport by Deng et al. (2017b). To the best of universality and robustness, Xue et al proposed a self-adaptive ABC algorithm based on the global best candidate (SABC-GB) for global optimization problem (Xue et al. 2018). To overcome the deficiencies of weak local search ability in genetic algorithms (GA) and slow global convergence speed in ant colony optimization (ACO) algorithm, the chaotic optimization method, multi-population collaborative strategy and adaptive control parameters were introduced into the GA and ACO algorithm to propose a genetic and ant colony adaptive collaborative optimization (MGACACO) algorithm for solving complex optimization problems (Deng et al. 2017c). Deng et al introduced an improved PSO algorithm to optimize the parameters of least squares support vector machines (LS-SVM) in order to construct an optimal LS-SVM classifier for fault diagnosis (Deng et al. 2017a). In addition, many others research also address the problem of optimizing emergency system using intelligent algorithms (Suder and Kahraman 2018; Zhao et al. 2016). Apart from these methods, another way to improve emergency system is based on expert system. Yang et al. (2013b) handed an information security risk-control assessment model combing VIKOR, DEMATEL, and ANP to solve the problem of conflicting criteria that show dependence and feedback. Hung (2011) proposed model which can effectively incorporate the key factors of precise costing, managerial constraints, competitive advantage analysis, and risk management into DSC forecasting and multi-objective production planning when design a supply chain. Fan et al. (2012) identified risk factors of IT outsourcing using interdependent information using an extended DEMATEL method. Fan et al. (2012) utilized fuzzy ordered weighted averaging (OWA) and the decision-making trial and evaluation laboratory (DEMATEL) approach to rank the risk of failure and then revise them to avoid risks. Other researches also investigate the expert system to improve emergency systems (Cebi et al. 2011; Karaşan and Kahraman 2018).

However, in the real world, it is impossible to improve all components and factors simultaneously because of the limitation of resources? To address this problem, a more effective way is to figure out the relations of factors and apply main efforts to improve those crucial and urgent factors referred as critical success factors (CSFs) (Somers and Nelson 2001). The study of critical success factors (CSFs) was developed by Bullen and Rockart (1981) as a method to enable decision maker 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 analyzed 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. The conception of CSF has been widely accepted especially in commercial and medical areas, but this notion is rarely applied in emergency management. One contribution of this paper is to introduce CSF into emergency management and establish an efficient way to optimize system. If the performances of these CSFs are improved, the whole system will also be significantly facilitated. In this situation, the attention should be paid on these CSFs (Bian et al. 2018; Kang et al. 2018a). In prior research, CSFs were usually defined by experts according to their experiences responding to cases. An inevitable problem is it always bears the subjectivity and ignorance of people, which will greatly influence the precision of evaluation results. Few researches make attempts to solve this question. To bridge this gap, we provide a new perspective for identifying CSFs using multicriteria decision-making methods. Different from former researches which transformed evaluations of experts into crisp numbers using defuzzification methods, then using other mathematical tools such as DEMATEL, VIKOR, TOPSIS to conduct further processing (Jatoth et al. 2018; Senvar et al. 2014). Our method is not only consider this issue in single perspective, but from a more comprehensive point. Besides, the uncertainty and fuzziness of experts evaluations are emphasized in the proposed method. Under this thrust, the evaluations in form of intuitionistic fuzzy numbers (IFNs) are transformed into basic probability assignments (BPAs). Then we aggregate them by combination rules, a comprehensive BPA which contains uncertainty and fuzziness will be handed out. To model relationships among different factors, the direct and indirect relations are taken into consideration simultaneously by using DEMATEL method. Noticed that there is no defuzzification in the model, thus the information loss is minimized. At last, we combine DEMATEL with BPAs to find final results in different perspectives, which are another originality of our research.

According to existing researches, a key problem is that relations among influential factors in emergency management are without consideration (Bian and Deng 2018; Fei et al. 2017). In our paper, decision-making and trial laboratory (DEMATEL) is utilized to quantify interactions between different factors in a complicated environment (?). To the best of our knowledge, it is the first time that the interactions among different factors are taken into consideration when comes to emergency management. Since this assumption satisfies reality better, the proposed method has a promising application in industrial fields when designing an emergency system. Our proposed enhanced fuzzy evidential DEMATEL consists of several steps. Firstly, we multiple experts are invited to assess direction relations from both positive and negative perspectives. The results are in the form of IFNs. Secondly, transform the IFNs into BPAs and use combination rules to fuse them. Thirdly, we measure uncertainty of BPAs and discount BPAs considering their uncertainty. Finally, DEMATEL is utilized to figure out the categories of cause factors and effect factors, in this study, the cause factors are identified as CSFs. It should be noticed that we obtain results from two perspectives which are more comprehensive.

The remaining of this paper is organized as follows: Sect. 2 starts with the preliminary knowledge which is the theoretical basis for our work. The proposed enhanced fuzzy evidential DEMATEL is presented in Sects. 3 and 4 gives an example to testify the efficiency of the proposed approach; in Sect. 5, we discuss and analysis the ability of our model to identify CSFs and capability to deal with uncertainty and fuzziness; finally, the conclusion is made in Sect. 6.

2 Preliminaries

In this section, some preliminaries are briefly introduced as below.

2.1 Basics of evidence theory

Dempster–Shafer evidence theory (also known as D–S theory and evidence theory) is regarded as an useful tool to tackle with imprecise and uncertain information by assigning the probability to the subsets of the set of multiple objects rather than individual objects. It is a generation of probability theory. The most crucial tool of D–S theory is its combination rules which allow it to fuse multiple information sources. Due to its ability to deal with imprecise and uncertain information, it is widely used in many fields such as risk analysis (Zheng and Deng 2018), supplier selection (Liu et al. 2018a), information fusion (Smarandache and Dezert 2015; Xu and Deng 2018; Wang et al. 2017), target recognition (Liu et al. 2017) and classification (Liu et al. 2018b), and multiple-attribute decision-making (Yang and Singh 1994; Yang and Xu 2002; Yang et al. 2006; Han and Deng 2018). There are also some heated topics about Dempster–Shafer theory like the uncertainty measurement (Song et al. 2014; Yager 1999), the conflict management (Bronevich and Rozenberg 2015; Lefevre et al. 2002, 2000; Wang et al. 2016) and combination of evidence (Han et al. 2008; Yang et al. 2013; Meza et al. 2016; Shen and Tzeng 2015). For completeness of the explanation, we introduce some concepts below:

Let Ω be a nonempty finite set and its elements are $\{\theta_1, \theta_2, \cdots, \theta_n\}$. Let 2^{Ω} be the set of all subsets of Ω, denoted $2^{\Omega} = \{\emptyset, \{\theta_1\}, \{\theta_2\}, \cdots \{\theta_n\}, \{\theta_1, \theta_2\}, \cdots, \{\theta_1, \theta_2 \cdots, \theta_n\} \cdots, \theta\}$.

The $\emptyset$ is empty set and θ is whole set. In D–S theory (Shafer 1976), mathematically a basic probability assignment (BPA) is a mapping: $2^{\Omega} \rightarrow [0, 1]$ that satisfies

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

and

$$m(\emptyset) = 0 \tag{2}$$

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

$$m(A) = \frac{\sum_{B,C \subseteq \Omega, B \bigcap C = A} m_1(B)m_2(C)}{1 - K} \tag{3}$$

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 rule is not meaningful.

2.2 Uncertain measure in evidence theory

Uncertainty is widespread in universe Zhang et al. (2018a, b). How to tackle with uncertainty contained in the information has attracted multitude attention in these years. Many measures of uncertainty are handed up to solve this heated problem Deng et al. (2018); Kang et al. (2018b). According to Klir and Yuan (1995), these methods can be classified as three categories: fuzziness, discord and nonspecificity. The discord and nonspecificity could be united under the term total uncertainty. Plenty of measures of total uncertainty has been developed such as Shannon entropy (2001), Hartley measure (1928), Ambiguity measure (AM) (Harmanec and Klir 1994). Among these measures of total uncertainty, the most representative one is Pal et al. (1992):

Let Ω be a framework of discernment with k elements, $\Omega = \{x_1, x_2, \cdots, x_k\}$, and let m be a BPA defined on Ω. The total uncertainty is defined as follows:

$$H(m) = -\sum_{x \in \Omega} m(x) \log_2 \frac{m(x)}{|x|} \tag{4}$$

where $|.|$ is the cardinality of each element. It could be regarded as a generation of Shannon's entropy and it satisfies subadditivity, additivity, continuity and other superior properties.

2.3 DEMATEL method

The methodology of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) was originally developed by Battelle Memorial Association in Geneva, is an effective method for analyzing direct and indirect relationship between components in the system in respect to its severity and type. According to its capability to handle complex relationships among the factors, it has a wide application in diverse fields such as critical factors identification (Bai and Sarkis 2013; Shieh et al. 2010; Wu 2012; Zhou et al. 2011), supply chain management (Patil and Kant 2014; Mangla et al. 2016; Tseng and Lin 2009), service management (Tzeng et al. 2007; Wu 2008), failure mode and effects analysis (FMEA) (Lin and Jia 2016; Liu 2016; Tsai et al. 2017). Besides, DEMATEL method also combines with fuzzy sets so it could tackle complicate situations under uncertainty and fuzziness (Deng and Deng 2018; Luthra et al. 2016; Sangaiah et al. 2015; Zheng and Deng 2017). The main procedure of DEMATEL is 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 DRM of influential factors.

In this step, we transform the weighted direct graph to Direct Relation Matrix (DRM), for n influential factors F_1, F_2, $\cdots$, F_n, DRM 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 DRM.

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

$$N = \frac{D}{\max_i(\sum_{j=1}^{n} d_{ij})} \tag{5}$$

Step 4 Calculate TRM.

Total direct relations Matrix(TRM) contains direct and indirect relation among factors, the calculation is shown in the following:

$$T = N(I - N)^{-1} \tag{6}$$

where I is a $n \times n$ identity matrix. R is the sum of rows and C is the sum of columns in the matrix T. The value of $R + C$ indicates degree of relation between each alternative with others and alternatives having higher values of $R + C$ have closer relationship with another and those having lower values of $R + C$ have less relationship with others. $(R + C)$is defined as prominence, indicating the importance of factors in the system. The value of $R - C$ represents severity for

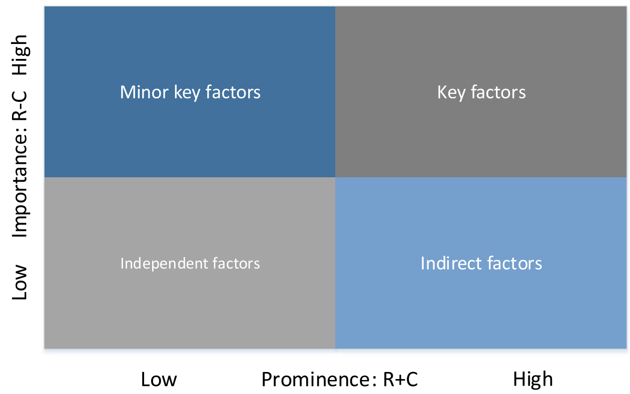

Fig. 1 The DEMATEL Map

influence of each alternative. Alternatives with higher value of $R - C$ have higher influence to another and are assumed to have higher priority, and those having lower values receiving more influence from another are assumed to have lower priority. The DEMATEL map is shown in Fig. 1. The concrete algorithm is displayed in Table 1.

3 The procedure of enhanced fuzzy evidential DEMATEL to identify CSFs in emergency management

In this section, based on DEMATEL method and evidence theory with its total uncertainty measure, a novel method called enhanced fuzzy evidence DEMATEL to identify the critical CSFs is proposed. The evidence theory is used to fuse the opinions from group members and total uncertain measurement is implemented to analyze the fuzziness and uncertainty of fused BPAs by discounting them. After that, DEMATEL method is adopted to figure out the total relations of factors, and classify the factors into cause and effect category. The cause factors will be identified as the critical CSFs in the emergency management and their order will be depended on their quantities. The flow chart of our method is shown in Fig. 2. The procedure of identifying the critical CSFs can be divided into 6 steps.

Step 1: Expert evaluation on the factors in emergency management system

At the first step, some experts will identify and evaluate the factors as well their interactions with each other. A linguistic assessments of direct relations among each pair of factors will be acquired in this step. The outcome of the experts' assessments will be presented as matrix of intuitionistic fuzzy sets.

Step 2: Turn the linguistic assessment into direct relation matrix with BPAs

To fuse the multiple evaluations from different experts, we transform the matrix of intuitionistic fuzzy sets into matrix with BPAs. In this way, we could implement D–S combination rules to aggregate every elements in the different matrixes handed by experts. After conducting this step, we could obtain a fused matrix of BPAs.

Step 3: Calculate the credibility of each BPAs in the fused matrix of BPAs

The fused BPAs always contain fuzziness and uncertainties due to the ignorance of experts and deviations of evaluations. Thus, the credibility of each BPA is not equal. To acquire a precise decision, the impact of BPAs which contain more uncertainties and fuzziness should be impaired. We use total uncertainty measure to evaluate the credibility of each BPA in the fused matrix and then discount them by their credibility. The details are as follows

(1) Calculate the total uncertainty of each BPAs H_i in the fused matrix. A total uncertainty measure matrix will be obtained.

(2) Obtain credibility matrix including all credibility of BPAs in fused matrix, credibility could be obtained from equation (7):

$$\mathrm{Cred}_i = \frac{1}{1 + H_i} \tag{7}$$

Step 4: Obtaining the Comprehensive Direct Relation Matrix

Table 1 Algorithm Transformation of DRM to TRM in DEMATEL

Algorithm1: Transformation of DRM to TRM in DEMATEL

Input: A DRM $D = (d_{ij})_{n\times n}\ (i, j = 1, 2, \cdots, n))$ in DEMATEL;
Output: A TRM $T = (t_{ij})_{n\times n}(i, j = 1, 2, \cdots, n))$ of D in DEMATEL;
Initial E=eye(n);
for all i do
$SR(i, 1) = \sum_{j=1}^{n} d_{ij}$; %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 $T = N(I - E)^{-1}$

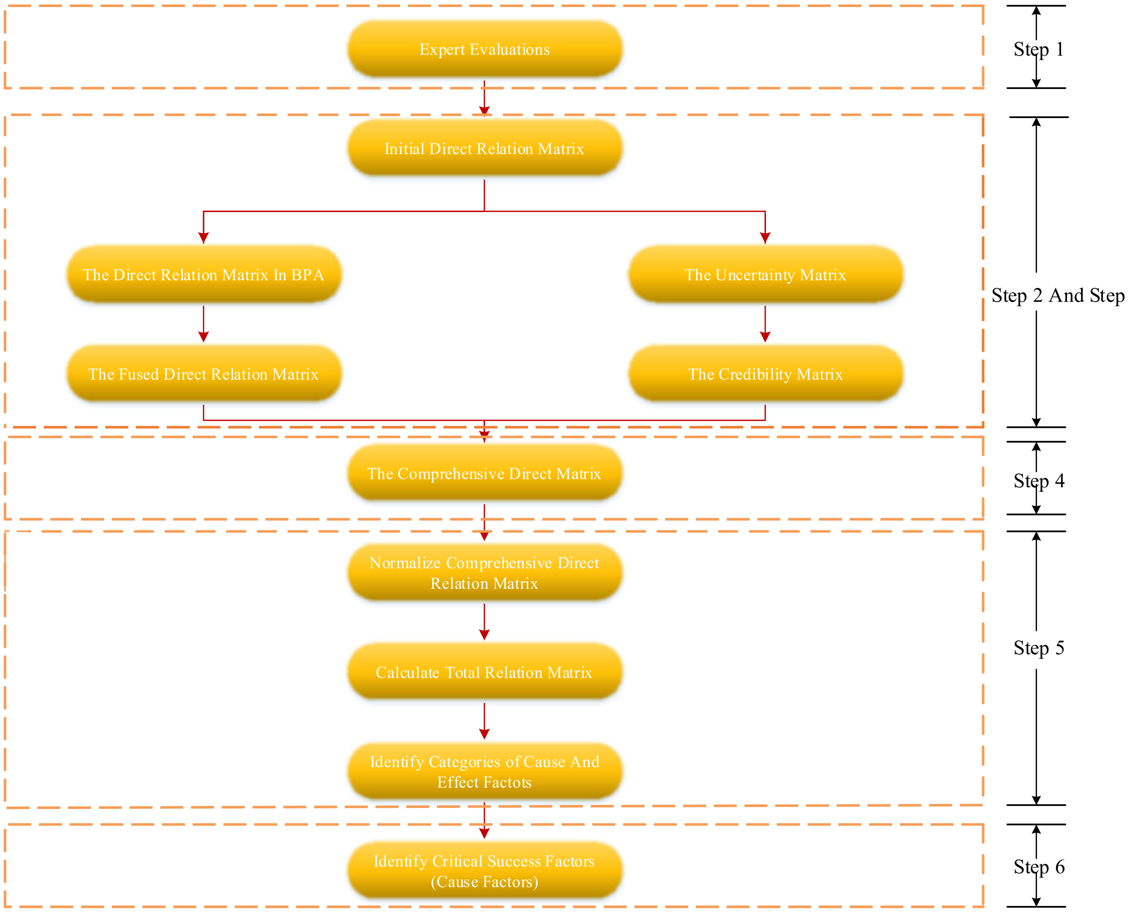

Fig. 2 The flow diagram of our enhanced fuzzy evidential DEMATEL to identify critical success factors

The Comprehensive Direct Relation Matrix is a combination of credibility matrix and direct relation matrix with BPAs. The element in the Comprehensive Relation Matrix is calculated by multiplying BPA with its credibility. In this way, we could consider their fuzziness when we tackle them.

Step 5: Applying DEMATEL method

DEMATEL method is used to calculate the total relation according to the basic probability of each proposition. In this way, the importance of factors can be visualized from different aspects by utilizing DEMATEL approach.

Step 6: Identifying CSFs

Based on Comprehensive Direct Relation Matrix, the sum of each row $R_i(i = 1, 2, 3, 4, \ldots)$ and each column $C_i(i = 1, 2, 3, 4, \ldots)$ could be calculated. The factors will be classified as cause and effect category according to the value of $(R_i - C_i)$. From the positive side, the factor i is classified as a cause factor if $(R_i - C_i) > 0$ while a factor is a effect factor if $(R_i - C_i) < 0$. From the negative side, the factor i is classified as a cause factor if $-(R_i - C_i) > 0$ while a factor is a effect factor if $-(R_i - C_i) < 0$. The factors are evaluated in both positive side and negative side.

4 A case study

An illustration of identifying CSFs in emergency management is presented in this section. Following the procedure of proposed enhanced fuzzy evidential DEMATEL to handle 10 system factor which influence emergency management are figured out in Table 2.

Step 1: Expert evaluation on the factors in emergency management system

Three experts who come from Reliability and Risk Engineering and Management in Vanderbilt University, USA, are invited to make assessments about influences and relationships among factors. To quantify the relationship between evaluation factors, they give their linguistic assessments in the forms of intuitionistic fuzzy sets representing which factors have direct relation with each other. The raw data in forms of intuitionistic fuzzy sets are obtained in Tables 3, 4 and 5. Intuitionistic fuzzy number (0.2, 0.7) means the membership of F1 has direct relation with F4 is 0.2, the non-membership of F2 has relation with F4 is 0.7(F2 doesn't have relation with F4).

Table 2 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 3 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 4 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)

Step 2: Turn the linguistic assessment into direct relation matrix with BPAs

In order to aggregate multiple information from experts, the intuitionistic fuzzy sets would be transformed into BPAs. Still taking (0.2,0.7) as an example, the transferred BPA is: $m(Y) = 0.2$, $m(N) = 0.7$, $m(Y, N) = 0.1$ where the $m(Y)$ indicates the degree of F2 has direct relationship with F4, $m(N)$ refers degree of F2 doesn't have relationship with F4. $m(Y, N)$ means the uncertainty of this BPA. After transforming all the intuitionistic fuzzy sets to BPAs, we implement D–S combination rules to fuse them and get a Fused Direct Relation Matrix which contains $(m(Y), m(N), m(Y, N))$, we divide them into three matrixes called positive matrix including $m(Y)s$, negative matrix whose elements are $m(N)s$ and matrix with $m(Y, N)s$, these are shown in Tables 6, 7 and 8.

Table 5 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 6 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 7 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

Step 3: Calculate the credibility of each BPAs in the fused matrix of BPAs

Now, based on the fused BPAs in the fused direct relation matrix, we analyze the uncertainty and fuzziness of them and discount them with its credibility. Firstly, we calculate the total uncertainty of the fused BPAs. Based on the total uncertainty, we calculate the credibility of each BPAs. The results are displayed in Tables 9 and 10.

Step 4: Obtaining the Comprehensive Direct Relation Matrix

The Comprehensive Direct Relation Matrix is combined with the credibility matrix as well as Fused Direct Relation Matrix. It is the initial state of the DEMATEL procedure. Tables 11 and 12 present the Comprehensive Direct Relation Matrix in positive ($m(Y)$) and negative ($m(N)$). Both positive and negative aspects will be taken into consideration for analyzing CSFs.

Step 5: Applying DEMATEL method

Table 8 The value of $m(Y, N)$ 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 9 The total uncertainty matrix of the fused BPAs

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.0133	0.0114	0.0764	0.4549	0.5052	0.9452	0.0248	0.4141	0.7050
F2	0.5717	0	1.0242	0.9881	0.8899	0.5746	0.7434	1.0903	0.6193	0.5386
F3	0.9115	0.3823	0	0.1902	0.8155	0.4102	0.1602	1.0045	1.0520	0.3336
F4	0.3779	0.3353	0.0243	0	0.4866	0.0481	0.1248	0.5939	0.2525	0.2439
F5	0.7613	0.9103	0.4693	0.7579	0	0.2119	0.3721	0.7661	1.0347	0.7826
F6	0.9575	0.9431	0.6344	0.6389	1.0234	0	0.9761	0.9817	0.9373	1.0041
F7	0.9861	0.1351	0.8248	0.0083	0.0566	0.2080	0	0.2991	0.0866	0.2677
F8	0.6467	0.7387	0.4895	0.0243	0.0261	0.9828	0.8223	0	0.4521	1.1345
F9	0.7129	0.5547	0.9710	0.0720	0.3966	1.1139	0.2525	0.6111	0	1.0853
F10	0.8935	0.8384	0.8875	0.1292	0.6232	0.9746	0.9015	0.1644	1.0665	0

Table 10 The credibility matrix of the fused BPAs

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1	0.9869	0.9887	0.9290	0.6873	0.6644	0.5141	0.9758	0.7072	0.5865
F2	0.6363	1	0.4940	0.5030	0.5291	0.6351	0.5736	0.4784	0.6176	0.6499
F3	0.5231	0.7234	1	0.8402	0.5508	0.7091	0.8619	0.4989	0.4873	0.7499
F4	0.7257	0.7489	0.9763	1	0.6727	0.9541	0.8890	0.6274	0.7984	0.8039
F5	0.5678	0.5235	0.6806	0.5689	1	0.8252	0.7288	0.5662	0.4915	0.5610
F6	0.5109	0.5146	0.6118	0.6102	0.4942	1	0.5060	0.5046	0.5162	0.4990
F7	0.5035	0.8810	0.5480	0.9918	0.9464	0.8278	1	0.7698	0.9203	0.7888
F8	0.6073	0.5751	0.6714	0.9763	0.9746	0.5043	0.5488	1	0.6887	0.4685
F9	0.5838	0.6432	0.5074	0.9328	0.7160	0.4731	0.7984	0.6207	1	0.4795
F10	0.5281	0.5440	0.5298	0.8856	0.6161	0.5064	0.5259	0.8588	0.4839	1

In this step, we adopt DEMATEL method to analyze the relationship among factors. By iterating many times, the Total Relation Matrix can be obtained. The sum of each row and each column in the Total Relation Matrix is a effective tool to quantify the importance of each factor. The Total Relation Matrixes in positive side and negative side are detailed in Tables 13 and 14.

Step 6: Identifying CSFs

In the sixth step, factors are classified into cause and effect categories according to their value $R - C$. The factors with higher values of $R - C$ are classified as cause factors. The cause factors are also CSFs because they affect other factors than being effected. Based on their categories, we rank them in term of $R - C$ in positive and negative aspects. The result is shown in Tables 15 and 16. Since those cause factors (values of $R - C$ bigger than 0) are classified as CSFs, five factors F2≻ F9≻ F10≻ F6≻ F8 are classified as CSFs in emergency management from positive perspective while five factors F2 ≻ F6 ≻ F9 ≻ F10 ≻ F5 are classified as CSFs in emergency management from negative perspective. The cause–effect diagram is constructed in Fig. 3. The result

Table 11 The Comprehensive Direct Relation Matrix from positive side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.0009	0.0010	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 12 The Comprehensive Direct Relation Matrix from negative side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0	0.9989	0.9990	0.9914	0.9069	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 13 The fused Total Relation Matrix in positive side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.1138	0.0347	0.0348	0.0085	0.0376	0.0614	0.2006	0.4221	0.0437	0.0801
F2	0.3427	0.0966	0.1668	0.0775	0.1780	0.2417	0.3247	0.3605	0.2397	0.1104
F3	0.1112	0.0460	0.0299	0.0133	0.0572	0.0456	0.0758	0.1809	0.0856	0.0442
F4	0.0340	0.0211	0.0115	0.0027	0.0253	0.0112	0.0243	0.0535	0.0173	0.0181
F5	0.1234	0.0909	0.2268	0.0489	0.0335	0.0526	0.1052	0.1728	0.1365	0.0738
F6	0.2187	0.1524	0.0894	0.0460	0.1233	0.0607	0.1751	0.2412	0.1142	0.1167
F7	0.1809	0.0281	0.0611	0.0048	0.0176	0.0393	0.0804	0.3292	0.0262	0.0484
F8	0.2499	0.0649	0.0537	0.0096	0.0297	0.0897	0.2230	0.1810	0.0497	0.1155
F9	0.2242	0.2309	0.1355	0.0237	0.0736	0.1450	0.3919	0.4185	0.0828	0.1481
F10	0.2581	0.0974	0.1014	0.0165	0.0795	0.1186	0.1988	0.4519	0.1369	0.0704

in the last section suggests that By averaging importance of each factor in positive and negative, we acquire final importance ranking of factors in emergency system as presented in Table 17 , in which F2 ≻ F9 ≻ F6 ≻ F10 ≻ F5 are identified as CSFs. According to we have discussed in Sect. 2, the emergency systems's performance can be drastically improved if these CSFs are optimized. Therefore, a better way for practitioner and manager is to pay attention on these factors and devote main resources to optimize them.

5 Discussion

The results in the last section claim that in the emergency management, F2 (reasonable organizational structure and clear awareness of responsibilities)≻ F9 (clear procedure of reporting and submitting information) ≻ F10 (application of modern logistics technology) ≻ F5(regular organization of simulated disaster exercise) are CSFs. In this section, we further our discussions on superiorities and contributions of our proposed method.

Table 14 The fused Total Relation Matrix in negative side

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.0907	0.2701	0.2647	0.3068	0.2191	0.2289	0.1480	0.0703	0.2029	0.2095
F2	0.0429	0.0524	0.0842	0.1163	0.0731	0.0672	0.0610	0.0592	0.0570	0.1308
F3	0.1316	0.2258	0.1282	0.2880	0.1928	0.2313	0.2256	0.0902	0.1571	0.2313
F4	0.1989	0.2708	0.2963	0.2441	0.2628	0.3121	0.2621	0.1530	0.2545	0.2787
F5	0.1235	0.1561	0.1133	0.2036	0.1090	0.2186	0.1761	0.1100	0.1222	0.1638
F6	0.0784	0.1081	0.1510	0.1830	0.1177	0.0894	0.1158	0.0831	0.1206	0.1222
F7	0.1223	0.2573	0.1953	0.3277	0.2720	0.2659	0.1272	0.0795	0.2450	0.2499
F8	0.0950	0.1784	0.1935	0.2854	0.2499	0.1776	0.1209	0.0621	0.1865	0.1486
F9	0.1278	0.1049	0.1334	0.2417	0.1807	0.1408	0.0874	0.0573	0.0789	0.1222
F10	0.0823	0.1503	0.1407	0.2358	0.1559	0.1465	0.1331	0.0502	0.1088	0.0952

Table 15 Rank factors in positive

Order	R	Order	C	Order	$R-C$
F2	2.1385	F8	2.8117	F2	1.2754
F9	1.8744	F1	1.8568	F9	0.9418
F10	1.5295	F7	1.7999	F10	0.7039
F6	1.3376	F9	0.9327	F6	0.4717
F8	1.0666	F3	0.9109	F5	0.4091
F5	1.0643	F6	0.8659	F4	−0.0326
F1	1.0375	F2	0.8630	F3	−0.2210
F7	0.8160	F10	0.8256	F1	−0.8193
F3	0.6899	F5	0.6553	F7	−0.9839
F4	0.2190	F4	0.2516	F8	−1.7450

Table 16 Rank factors in negative

Order	R	Order	C	Order	$R-C$
F4	2.5332	F4	2.4325	F1	0.9182
F7	2.1421	F6	1.8782	F8	0.8830
F1	2.0109	F5	1.8329	F7	0.6848
F3	1.9018	F2	1.7741	F3	0.2013
F8	1.6979	F10	1.7522	F4	0.1008
F5	1.4962	F3	1.7005	F9	−0.2583
F10	1.2988	F9	1.5333	F5	−0.3372
F9	1.2751	F7	1.4573	F10	−0.4534
F6	1.1694	F1	1.0934	F6	−0.7089
F2	0.7440	F8	0.8149	F2	−1.0302

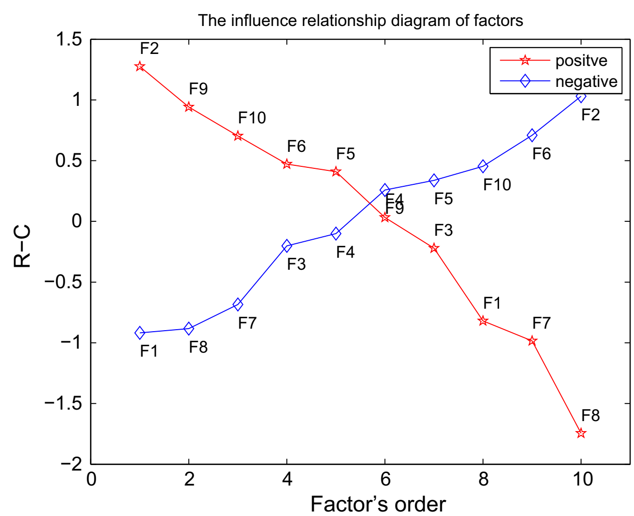

Fig. 3 The cause–effect diagram

5.1 Assessment 1: The capability of enhanced evidential DEMATEL to identify CSFs

Figure 4 shows the comparison of our enhanced fuzzy evidential DEMATEL with D-DEMATEL (Zhou et al. 2017) and Evidential DEMATEL (Li et al. 2014) in positive side and negative side. It can be seen that the rank of the factors in emergency management are coincided. The cause and effect factors in these three methods are also be considered in Table 18. All these three methods identify F2 (reasonable organizational structure and clear awareness of responsibilities) as the most critical success factor in 10 factors. F9 (Clear procedure of reporting and submitting information), F6 (Government unity of leadership to plan and coordinate as a whole), F10 (Application of modern logistics technology), F5 (Regular organization of simulated disaster exercise) are other common CSFs. Each CSF in the system is compared according to their value which is displayed in Fig. 5. Obviously, the values of each factor are very similar according to three different methods which also verifies our method's validness and effectiveness. From all we have discussed above, the factors classified as cause and effect factors are actually similar which proves the ability of our enhanced fuzzy evidential DEMATEL to identify CSFs in emergency management system.

Table 17 Factors influencing emergency management

Category	Ranking	Importance
Cause	F2 Reasonable organizational structure and clear awareness of responsibilities	1.1528
	F9 Clear procedure of reporting and submitting information	0.600
	F6 Government unity of leadership to plan and coordinate as a whole	0.5903
	F10 Application of modern logistics technology	0.5786
	F5 Regular organization of simulated disaster exercise	0.3729
Effect	F4 Education campaign on disaster prevention and response	−0.0667
	F3 Applicable emergency response plan and regulations	−0.2111
	F7 Timely and accurate relief needs assessment	−0.8343
	F1 Well-planned emergency relief supply system	−0.8684
	F8 The security of relief aids during distribution and transportation	−1.3140

5.2 Assessment 2: The ability to handle fuzziness and uncertainty

5.2.1 Divergence from positive side and negative side

The enhanced fuzzy evidential DEMATEL could tackle incomplete and uncertain information for it has superior sensitivity. The uncertainty and fuzziness are caused by lacking knowledge or ignorance to the situations. The uncertainty is always reflected from the derivations of positive perspective and negative perspective. This is very easy to understand, if experts are uncertain to the relations between influential factors, the value of $m(\theta)$ can be larger according to Sect. 3, and in this case the divergence between $m(Y)$ and $m(No)$ can be obvious which results in differences in positive perspective and negative perspective. Figure 6 shows the importance of the factors, and Table 19 shows the total uncertainty of factors derived from total uncertain of each BPAs in matrix. F1, F3, F4, F5 contain less total uncertainty so they have seemingly equal value in positive and negative side. Instead, F6, F8, F9, F10 have apparent deviations for their total uncertainty are larger.

5.2.2 MAE method

MAE method is introduced to evaluate the ability of three methods to handle with uncertainty and fuzziness, which is calculated by:

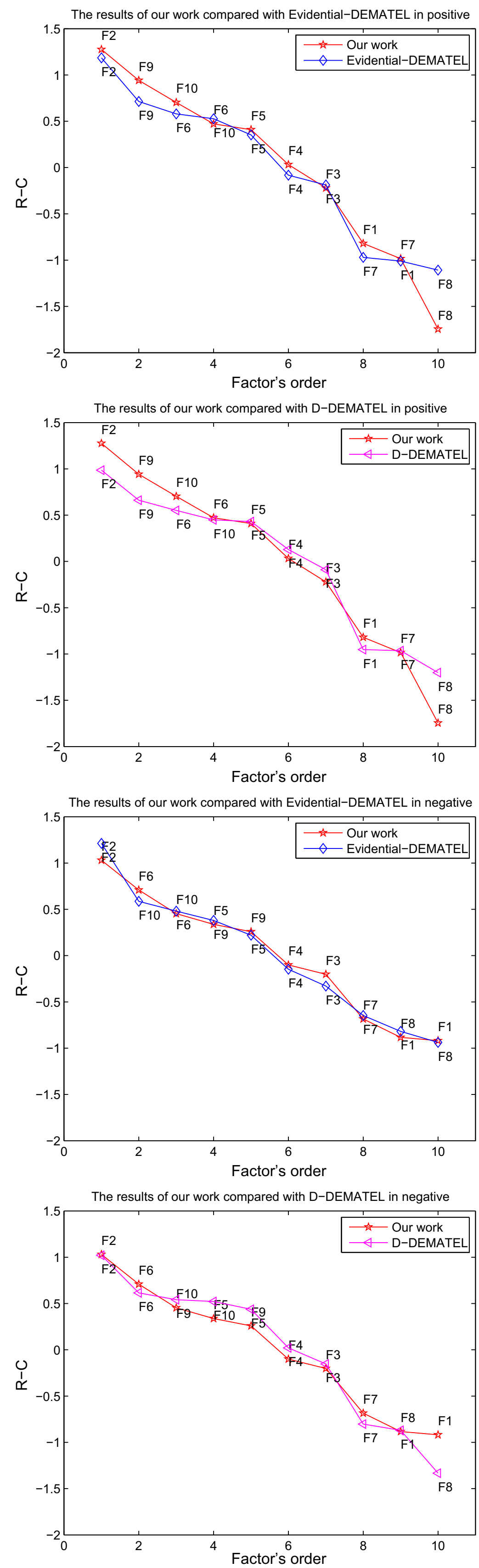

Fig. 4 The cause–effect order diagram

Table 18 The category of factors in emergency management

Category	Our work	Evidential DEMATEL	D-DEMATEL
Cause	F2	F2	F2
	F9	F10	F9
	F6	F9	F6
	F10	F6	F10
	F5	F5	F5
	–	–	F4
Effect	F4	F4	F3
	F3	F3	F7
	F7	F7	F1
	F1	F1	F8
	F8	F8	-

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N} |V_Y^i - V_N^i| \tag{8}$$

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. As shown in Table 20, our work's MAE is the biggest among these three methods which reveals that it could measure uncertainty in the experts' evaluations.

5.3 Assessment 3: Superiority of enhanced fuzzy evidential DEMATEL

Lots of researches have been dedicated to optimizing performance of emergency management. However, few of them take the interactions and relations among influential factors into consideration. They are also failed to explain how to select specific factors and whether it is valuable to be investigated. In addition, most of existing researches are confined on a narrow scope, it is urgent and necessary to improve the whole quality of emergency systems from a higher point.

Compared with existing researches, proposed enhanced fuzzy evidential DEMATEL has great capability to figure out total direct and indirect relations among factors then identifying those cause ones as CSFs. The goal of optimizing overall emergency system can be converted to optimizing CSFs in emergency system.

In addition, a comparison among enhanced fuzzy evidential DEMATEL, D-DEMATEL and evidential DEMATEL has been done, which is shown in Table 21.

- enhanced fuzzy evidential DEMATEL vs evidential DEMAETL: Since both of them can well address Subjectivity of experts evaluations, the enhanced fuzzy evidential DEMATEL considers fuzziness of linguistic scale and uncertainty of experts evaluations into considerations thus it is more accurate in applications.
- enhanced fuzzy evidential DEMATEL vs D-DEMATEL: While these two methods have prominent ability to deal with fuzziness of linguistic scale and subjectivity of experts, enhanced fuzzy evidential DEMATEL considers the uncertainty in experts' evaluations.

In a word, the reasonability of enhanced fuzzy evidential DEMATEL is analyzed by evaluations shown in Table 22. Based on the discussion above, compared with evidential DEMATEL and D-DEMATEL, enhanced fuzzy evidential DEMATEL satisfies reality better, so it can be widely applied in various areas.

6 Conclusions

A large amount of researches are presented to address the optimization of emergency systems due to the frequent occurrence of accidental events. Due to the limitation of resources, a more feasible way is to optimize CSFs since in some cases the resources are limited. In this paper, a novel method called enhanced fuzzy evidential DEMATEL which combines DEMATEL and Dempster–Shafer evidence theory is proposed to identify CSFs in emergency systems. The performance whole emergency system will be significantly facilitated after optimizing these CSFs. In this paper, evaluations of domain for relations between factors in emergency systems are presented as IFNs. Then it is converted to BPAs to model uncertainty and fuzziness. We combine these BPAs using combination rules. Next, we measure the uncertainty of fused BPA and discount the BPA responding to its uncertainty. Finally, DEMATEL is implemented to figure out the cause–effect categories of factors and those cause factors are identified as CSFs. In this paper. In this study six factors F2(reasonable organizational structure and clear awareness or responsibilities), F9 (clear procedure of reporting and submitting information), F6(government utility of leadership to plan and coordinate as a whole), F10(application of modern logistics technology), F5(regular organization of simulated disaster exercise) are identified as CSFs in emergency systems. The task of improving the whole system will be simplified into optimizing just six factors. Experts who assess these factors support this result.

Compared with other former methods such as D-DEMATEL and evidential DEMATEL, our proposed method addresses the uncertainty of results and subjectivity of experts simultaneously. It could be seen from the result that although the outcomes acquired from positive and negative are similar, the quantitative values of these two perspective have obvious differences. Because evaluations of relations between factors are inevitably containing ignorance of experts. In this perspective, our results are more reliable

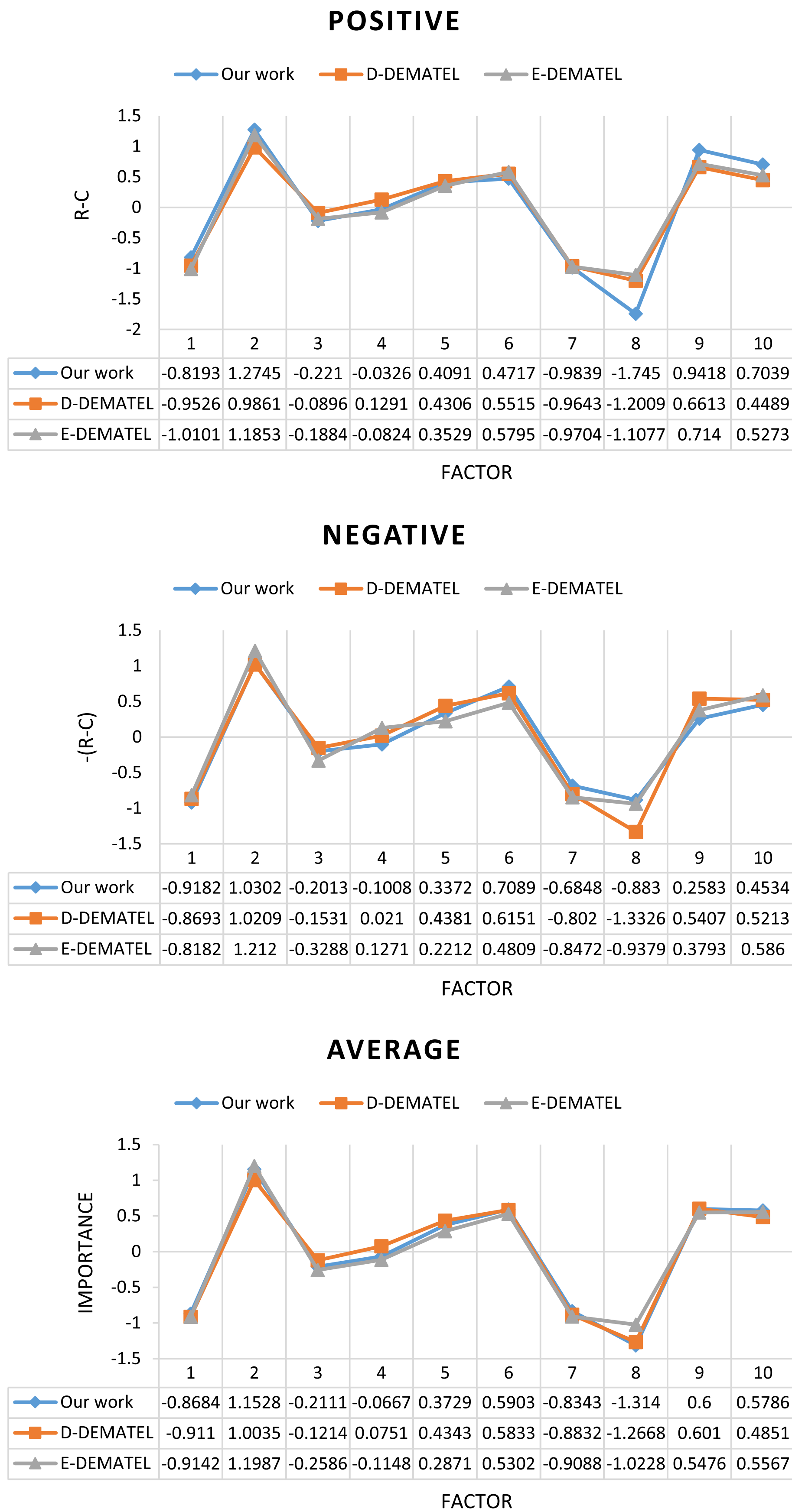

Fig. 5 The cause–effect diagram for each factor

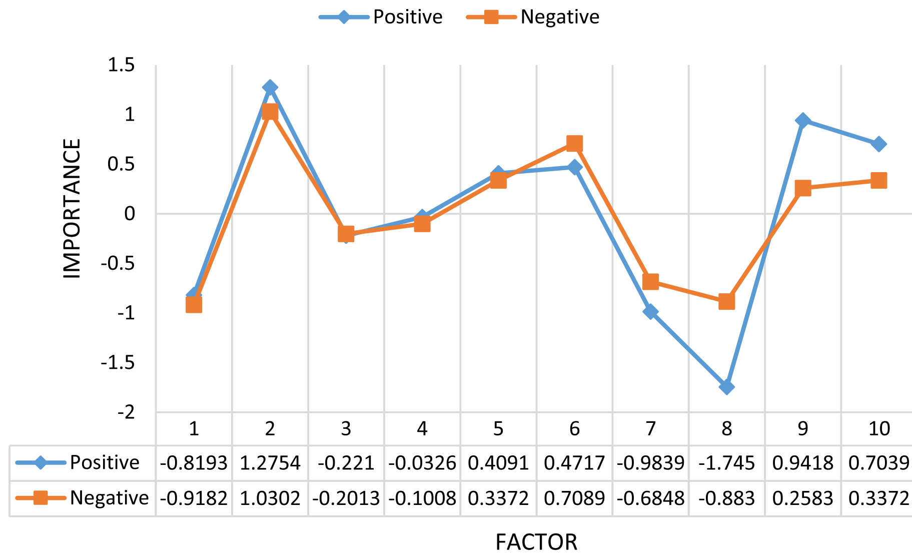

Fig. 6 The average cause–effect diagram for each factor

Table 19 The total uncertainty of each factor

F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
9.9649	11.8913	10.3964	5.3726	10.6390	13.1258	9.1704	10.8529	11.6851	12.5741

Table 20 The MAE of three methods

	Enhanced fuzzy evidential DEMATEL	Evidential DEMATEL	D-DEMATEL
MAE	0.2899	0.1340	0.0848

Table 21 Comparison of evidential DEMATEL, D-DEMATEL, enhanced evidential DEMATEL in linguistic evaluation

	evidential DEMATEL	D-DEMATEL	enhanced fuzzy evidential DEMATEL
Uncertainty of experts' evaluations	×	×	√
Fuzziness of linguistic scale	×	√	√
Subjectivity of experts' evaluations	√	√	√

Table 22 List of hybrid approaches based on FCM

Assessment 1	The capability of enhanced evidential DEMATEL to identify CSFs
Assumption	The classification and ranking of influential factors obtained by enhanced fuzzy evidential DEMATEL, evidential DEMATEL and D-DEMATEL are very similar, the proposed method is rational
Assessment 2	The ability to handle fuzziness and uncertainty
Assumption	The values of each influential factor differ in positive perspective and negative perspective, indicating uncertainty and fuzziness of experts' assessments
Assessment 3	Superiority of enhanced fuzzy evidential DEMATEL
Assumption	Enhanced fuzzy evidential DEMATEL can tackle with uncertainty of experts evaluations, fuzziness of linguistic scale, subjectivity of experts evaluation simultaneously, it is more applicable in practical

and precise compared with some existing methods. The main contribution and originality of this paper could be summarized as follows:

- A simple method to optimize emergency management using conception of CSF is introduced.
- The subjectivity and fuzziness of experts evaluations are minimized without any defuzzification and information losses.
- The uncertainty contained in BPAs are measured and taken into consideration.
- The relations between factors are clearly quantified in both positive and negative perspectives, the result is more reliable and comprehensive.

The proposed method can better meet uncertain and complicated reality. Thus, it is more applicable in real world. In the future, the method will be applied in practical industrial manufacturing, process control and other areas.

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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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