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ORIGINAL RESEARCH

# An improved evidential DEMATEL identify critical success factors under uncertain environment

Xueqian Shang[1] · Moxian Song[1] · Kai Huang[1] · Wen Jiang[1,2]

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**Abstract**
How to improve emergency management is still an open issue. In real application, since it is unpractical to optimize all of influential factors, a feasible way is to find out the critical success factors (CSF) to improve. In this paper, the existing evidential DEMATEL method is improved to be more reasonable. Inspired by belief entropy, a new function which is used to calculate the reliability of the information is defined. Then, DEMATEL method is applied on each fused BPA multiplied by the reliability coefficient to seek for a final result. Finally, five critical success factors are figured out. By optimizing these five factors, the effectiveness and efficiency of the whole emergency management system could be greatly promoted.

**Keywords** Emergency management · Critical success factor · Dempster–Shafer theory · Belief entropy · DEMATEL method

## 1 Introduction

As natural disasters and human accidents occur frequently in recent years, people are gradually aware of the importance of emergency management. Due to the fact that many factors of human, natural or equipment, disasters and accidents can not be completely avoided, an efficient emergency management has become the key to reducing the loss of disasters and ensuring the safety of public life and property.

However, how to build an efficient emergency management remains to be a puzzle now. There is a wide-spread concern over the issue of the optimization of emergency management. And a large quantity of research has been done. For example, Hernández and Serrano (2001) proposed the use of advanced knowledge models to support environmental emergency management as an adequate response to the current needs and technology. Mendonca et al. (2007) used the emergent interoperability approach to address unanticipated contingencies during emergency response. Huang et al. (2016) developed the Internet of intelligences to drive a risk radar monitoring dynamic risks for emergency management in community.

Since it is not realistic to improve all influencing factors, a more feasible way is used to identify the system requirements and to find out the most urgent and important factors. These factors are named critical success factors(CSFs) (Zhou et al. 2011). CSF has a wide application in many areas (Mangla et al. 2016; Ram et al. 2013, 2014; Disterheft et al. 2015). If these factors are improved, the efficiency of emergency management can be greatly facilitated. The process of figuring out CSFs can be considered as a multiple criteria decision making problem (Tseng 2011). There are many methods to analyze the combined information. In order to determine the CSFs in the emergency management, DEMATEL(Decision Making Trial and Evaluation Laboratory) method is applied to clarify the relationship among factors and calculate the most influential factors in this paper. One advantage of this method is that it can be combined with many theories and methods, such as grey theory (Bai et al. 2017), evidence theory (Xu and Deng 2019; Zhang

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✉ Wen Jiang
jiangwen@nwpu.edu.cn; jiangwenpaper@hotmail.com

Xueqian Shang
sxq1998@mail.nwpu.edu.cn

Moxian Song
songmoxiannwpu@126.com

Kai Huang
huangkainwpu@126.com

[1] School of Electronics and Information, Northwestern Polytechnical University, Xi'an 710072, Shaanxi, China

[2] Peng Cheng Laboratory, Shenzhen, China

et al. 2018), fuzzy numbers (Tsai et al. 2017, 2015) and AHP/ANP (Zhou et al. 2018; Pourahmad et al. 2015).

Many related works addressing the specific activity of emergency management have actually involved influence factors and experts' assessments about these factors. Former researchers focus on DEMATEL method with evidence theory. Li et al. (2014) used an evidential DEMATEL method to identify critical success factors in emergency management. However, they ignored the fact that the uncertainty of the information will also influence the result. With the generalization of D numbers (Mo and Deng 2019; Deng and Jiang 2019a, b), the DEMATEL is extended to D-DEMATEL (Lin et al. 2018; Zhou et al. 2017)

One of the main contributions in this paper is that it takes the uncertainty of the information into account. It is necessary to measure the uncertainty when information is fused (He and Jiang 2018b; Yang and Han 2016; Song et al. 2017; Deng and Jiang 2019c). Belief entropy is the method used in this paper to measure the uncertainty of the information, which is widely used in information fusion (Fu et al. 2019b; Xiao 2019a; Zhang et al. 2017a).

Evaluation given by experts is always linguistic assessment (Fu et al. 2015). In this paper, for the convenience of expressing uncertainty, linguistic values can be represented by intuitionistic fuzzy numbers(IFNs) (Pezhhan and Mansoori 2013; Chou et al. 2011; Xua and Xia 2012; Jiang et al. 2017). Then, IFNs are transformed into BPAs. By doing so, the uncertainty of evaluation is still kept. And then, Dempster–Shafer theory is adopted to aggregate the group assessment BPA matrix. Next, introduce belief entropy to calculate the reliability of the information before applying the DEMATEL method to identify the CSFs. Under this circumstance, CSFs obtained in this paper can be more reasonable.

The rest of this paper is organized as follows. Section 2 gives a brief introduction about Dempster–Shafer theory of evidence, belief entropy and DEMATEL method. Section 3 presents the procedure of CSFs identification in emergency management, and the result with an illustration is given in Sect. 4. Section 5 compares to the prior result and gives some discussion.

## 2 Preliminaries

In this section, some basic preliminaries, including evidence theory, DEMATEL, intuitionistic fuzzy set and belief entropy are briefly introduced.

### 2.1 Dempster–Shafer theory of evidence

Dempster–Shafer theory of evidence (Dempster 1967) has two main advantages in handling uncertain information. One is that Dempster–Shafer theory assign the probability to the subsets composed of multiple objects, which can directly express the uncertainty. The other one is that Dempster–Shafer theory has the ability to combine pairs of belief function to derive a new belief function. Reviewing the previous researches, evidence theory has been widely applied in uncertain environment and practicability in engineering, such as gender profiling (Fei et al. 2019; Ma et al. 2016), fault diagnosis (Dong et al. 2019; Moosavian et al. 2015; Zhang et al. 2017b, 2019), risk assessment (Zhang et al. 2016; Kang et al. 2019; Zhang et al. 2017a), decision making (He and Jiang 2018a) and pattern recognition (Fu et al. 2019a; Song et al. 2014; Jiang et al. 2019a; Zg et al. 2016; Geng et al. 2019).

A few basic concepts of Dempster–Shafer theory are introduced as follows.

**Definition 1** Let $\Omega$ be a set of mutually exclusive and collectively exhaustive events, indicated by

$$\Omega = \{E_1, E_2, \ldots, E_i, \ldots, E_N\} \tag{1}$$

where set $\Omega$ is called a frame of discernment. The power set of $\Omega$ is indicated by $2^\Omega$, namely

$$2^\Omega = \{\varnothing, \{E_1\}, \ldots, \{E_N\}, \{E_1, E_2\}, \ldots, \{E_1, E_2, \ldots, E_i\}, \ldots, \Omega\}. \tag{2}$$

The elements of $2^\Omega$ or subset of $\Omega$ are called propositions. For example if $A \in 2^\Omega$, $A$ is called a proposition.

For a frame of discernment $\Omega = \{E_1, E_2, \ldots, E_N\}$, a mass function is a mapping $m$ from $2^\Omega$ to [0, 1], formally defined by:

$$m: \quad 2^\Omega \rightarrow [0, 1] \tag{3}$$

which satisfies the following condition:

$$m(\varnothing) = 0 \quad and \quad \sum_{A \in 2^\Omega} m(A) = 1. \tag{4}$$

BPA is the most important concept in evidence theory and many operations on BPA are presented such as correlation (Jiang 2018; Jiang et al. 2019b), divergence (Song and Deng 2019; Fei and Deng 2018) and negation (Gao and Deng 2019). In addition, Dempster's rule of combination is used to combine two or more BPAs.

**Definition 2** Dempster's rule of combination, also called orthogonal sum, denoted by $m = m_1 \oplus m_2$, is defined as follows (Dempster 1967):

$$m(A) = \begin{cases} \frac{1}{1-K} \sum\limits_{B \cap C = A} m_1(B) m_2(C)\ , & A \neq \varnothing; \\ 0\ , & A = \varnothing \end{cases} \tag{5}$$

with

$$K = \sum_{B \cap C = \emptyset} m_1(B)m_2(C) \tag{6}$$

where $K$ is a normalization constant, called conflict coefficient of two BPAs. Only when $K < 1$ can the Dempster's combination rule be applicable.

## 2.2 Intuitionistic fuzzy set

The concept of Intuitionistic fuzzy set was introduced by Atanassov in 1986, which can ba defined as follows.

**Definition 3** Let $X = \{x_1, x_2, \dots, x_n\}$ be a finite universal set. An intuitionistic fuzzy set $A$ in $X$ is an object having the following form (Atanassov 1986):

$$A = \{< x_j, t_A(x_j), f_A(x_j) > | x \in X\} \tag{7}$$

where $t_A(x_j), f_A(x_j)$ are the degree of membership and non-membership of the element $x_j \in X$ to the set of $A \subseteq X$.

For each IFS $A$ in $X$, if

$$\pi_A(x_j) = 1 - t_A(x_j) - f_A(x_j), x_j \in X \tag{8}$$

then $\pi_A(x_j)$ is called the degree of indeterminacy membership of the element $x_j \in X$ to the set $A$.

For convenience, an IFN is expressed as follows (Xu and Yager 2006).

**Definition 4** An IFN a is defined as an ordered pair $(t_a, f_a)$ satisfying the following conditions:

$$t_a + f_a \leq 1, t_a \in [0,1], f_a \in [0,1]. \tag{9}$$

## 2.3 Belief entropy

Recently, a new belief entropy, named as Deng entropy (Deng 2016), is presented to measure the uncertainty of mass function, and it has some useful properties (He and Jiang 2018a; Abellan 2017).

**Definition 5** Belief entropy is defined as follows (Deng 2016):

$$E_d = -\sum_i m(F_i) \log \frac{m(F_i)}{2^{|F_i|} - 1} \tag{10}$$

where $m$ is a mass function defined on the frame of discernment, $F_i$ is a proposition in mass function $m$, and $|F_i|$ is the cardinality of $F_i$.

As can be seen in Eq. (10), the belief for each focal element $F_i$ is divided by a term $(2^{|F_i|} - 1)$ which represents the potential number of states in $F_i$. When $|F_i| = 1$, belief entropy will degenerate into Shannon entropy. Equation (11) means the results of Shannon entropy and belief entropy are identical when the belief is assigned to only one single element (Xiao 2019b; Huang et al. 2019; Ozkan 2018; Cui et al. 2019).

$$E_d = -\sum_i m(F_i) \log \frac{m(F_i)}{2^{|F_i|} - 1} = -\sum_{i=1}^{n} F_i \log F_i. \tag{11}$$

## 2.4 DEMATEL methods

The methodology of the Decision Making Trial and Evaluation Laboratory, first developed by the Battelle Memorial Association. Due to its advantages of analyzing total relations between components, DEMATEL has been successfully applied in diverse areas such as supply chain (Hsu et al. 2013; Lin 2013; Govindan et al. 2015), environment (Tsai et al. 2014), risk assessment (Chien et al. 2014; Zhou et al. 2014; Chang et al. 2013)and health-care waste management (Liu et al. 2015).

The basic steps of DEMATEL are shown as follows.

(1) Define quality feature which is a set of influential characteristics $F_1, F_2, \cdots, F_n$ that impact the sophisticated system. The pair-wise comparison scale may be designated four levels, where the scores of 0, 1, 2, and 3 represent "No influence", "Low influence", "High influence", and "Very high influence" respectively.

(2) The initial direct-relation matrix $M$ is a $n \times n$ matrix, in which $m_{ij}$ is denoted as the degree to which the factor $i$ affects the factor $j$. The direct-relation matrix $M = [m_{ij}]$ is obtained as the initial data of the DEMATEL analysis.

(3) Normalize the initial direct-relation matrix. The normalized direct relations of factors are a mapping from $m_{ij}$ to [0,1], defined as follows.

**Definition 6** For the framework of n influential characteristics $F_1, F_2, \cdots, F_n$, normalized matrix $N$ of direct relation matrix $M = [m_{ij}]$ is obtained by

$$s = \max\left(\sum_{j=1}^{n} m_{ij}\right) \tag{12}$$

$$N = \frac{M}{s} \tag{13}$$

(4) According to Eqs. (12) and (13), the elements of direct relation matrix are obtained. Hence, sub-stochastic matrix can be obtained through utilizing the normal-

ized direct relation matrix $N$ and absorbing state of Markov chain matrices, shown in Eq. (14). And this matrix $T$ is the total relation matrix which contains direct and indirect relations among factors.

$$T = \lim_{k\to\infty}(N + N^2 + \cdots + N^k) = N(I - N)^{-1} \tag{14}$$

where $I$ is the identity matrix.

(5) Based on the sum of each row $R_i (i = 1, 2, \ldots, n)$ and column $C_i (i = 1, 2, \ldots, n)$ of the total relation $T_{n\times n}$, $(R_i + C_i)$ and $(R_i - C_i)$ can be obtained. $(R_i + C_i)$ is defined as the prominence, showing the impact of $i$th influential factor and its degree of being impacted. $(R_i - C_i)$ indicates the importance of factors. If $(R_i - C_i) > 0$, the factor is a cause factor. If $(R_i - C_i) < 0$, the factor is an effect factor.

## 3 The proposed method

In this section, an evidential DEMATEL method with belief entropy to identify CSFs in emergency management is proposed.

In order to measure the uncertainty of the information, the belief entropy is used to take the mass of the universal set into account. The mass assigned to the universal set is determined by two factors. One is due to the evaluation given by experts is always linguistic assessment, when the linguistic assessment transformed into IFNs and BPAs, $m(\theta)$ expresses the ambiguity and uncertainty of language assessment. The other one comes from the step of normalizing the orthogonal sum (Eqs. (5) and (6)) obtained from combining.

The previous work (Deng 2016) has improved that the more the uncertainty of the BPA is, the greater the belief entropy is. So a new function which represents the reliability can be defined as follows.

$$R = \frac{1}{1 + E_d} \tag{15}$$

where $E_d$ is the belief entropy defined in Definition 5. This formula should satisfy two conditions. First, its value decreases with the increase of information uncertainty. Second, its value is in the range of zero to one.

Apart from the reliability function mentioned above, in the proposed method, intuitionistic fuzzy set could be implemented to measure ambiguous concepts associated with human beings' subjective judgement. And Dempster–Shafer theory of evidence is used to fuse group opinions to obtain the initial direct-relation matrix. DEMATEL method is adopted to analyze the total relations of factors, and classify these factors into cause and effect category. The cause factors will be finally identified as CSFs in emergency management. To describe the proposed method in a more intuitive way, a flowchart is illustrated in Fig. 1 shows.

Based on the proposed method, the detailed procedures of identifying CSFs in emergency management are described as follows:

(1) Factors which influence the emergency management should be figured out through investigation. Then, experts would give their judgement of the interaction between each pair of factors. In this step, the linguistic and ambiguous assessment of direct relations among factors are obtained.

(2) Turn the linguistic evaluation into IFN matrices to express the relations. For combining the group IFN matrixes efficiently, IFN matrixes are converted into BPA matrixes. Thus, by applying Dempster's rule of combination in Eqs. (5) and (6) to every element of the BPA matrixes, a matrix which represents the initial relation can be constructed.

(3) Apply belief entropy in Eq. (10) to calculate the belief entropy of every element of the initial matrixes. A matrix which the element measures uncertainty of BPA can be obtained. Substitute belief entropy into Eq. (15) to obtain a new matrix whose element can be a coefficient to multiply with BPA.

(4) Multiply the corresponding elements in the two matrixes which are obtained in process (2) and (3) to obtain a new comprehensive matrix, which takes the uncertainty of the information into account.

(5) Use DEMATEL method to calculate the total relation according to the basic probability number of each proposition. In this way, DEMATEL approach is utilized in the degree of direct relation of each factor.

(6) Identify CFSs in comprehensive consideration of the indexes $R - C$ on the basic probability number of each proposition. Considering the order of each factor, the ones which are more important and can greatly improve the efficiency of the system can be found out if these factors are optimized. Factors of this kind are definitely CSFs.

## 4 Critical success factor analysis using the proposed method

In this section, the improved evidential DEMATEL with belief entropy is applied to emergency management. Following the procedure of the proposed method, ten system factors which influence emergency management and the relationship between evaluation factors are figured out, as shown in Table 1 (Li et al. 2014). Since many related works addressing the specific activity of emergency management have actually involved influence factors and experts'

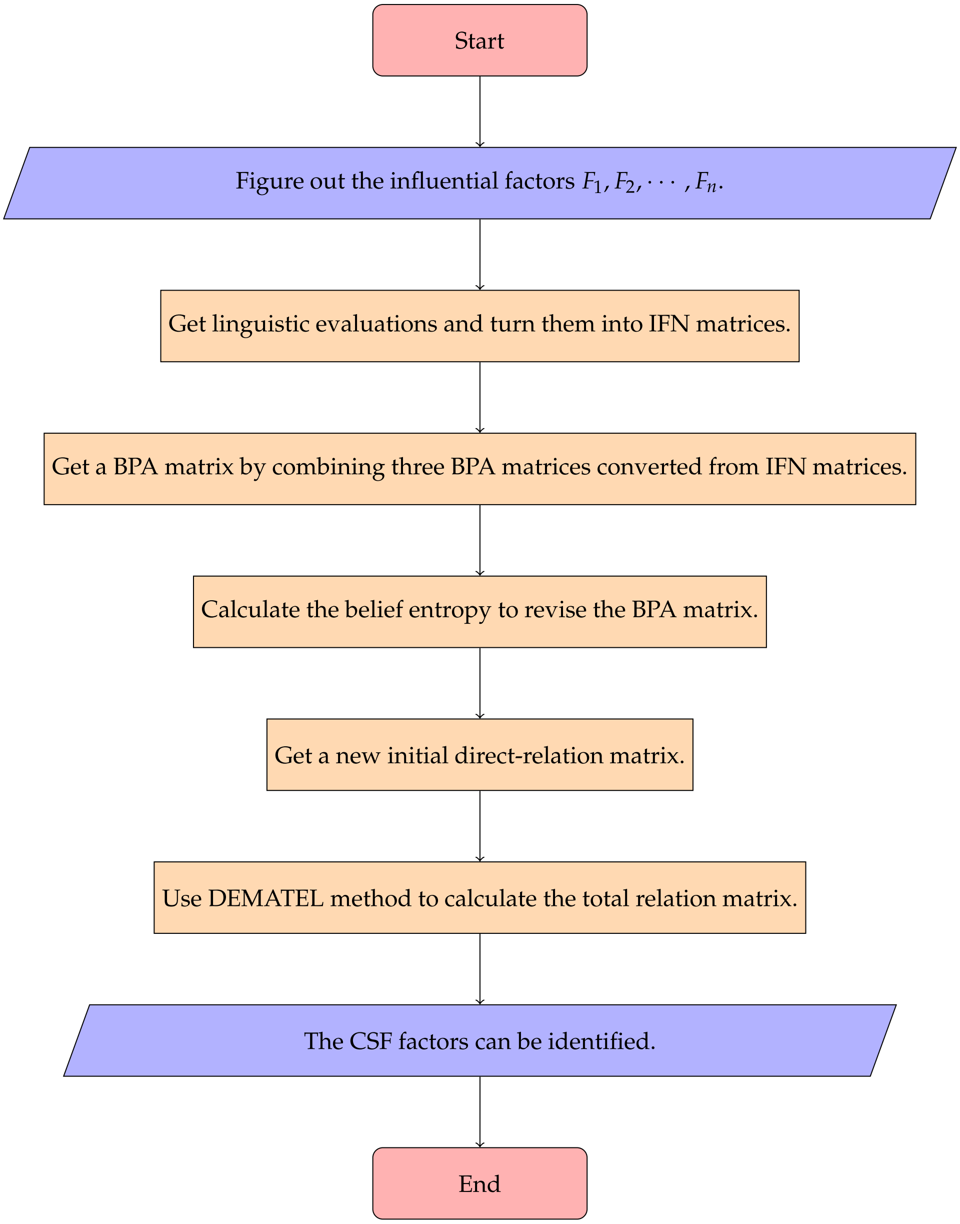

**Fig. 1** The flowchart of the proposed methods

**Table 1** Factors influence emergency management (Li et al. 2014)

| 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 |

assessments about these factors, so it is a feasible way to use some information from prior researches. The complete process of converting linguistic assessments to BPA can be referred to in (Li et al. 2014).

The previous work (Li et al. 2014) asks three experts who come from different working backgrounds to make assessments in terms of influences and relationship among factors. They give their linguistic assessments about the influence, which factors have direct impacts on each other. These assessments are converted into IFN matrixes. Thus, the initial direct relation matrixes whose elements are IFNs are obtained. Then, IFNs are transformed into BPAs. Next, Eqs. (5) and (6) are applied to aggregate BPA matrixes of the three experts to get a comprehensive BPA matrix whose elements are $(m(Y), m(N), m(\theta))$. Due to space limitation, this comprehensive matrix (Li et al. 2014) is divided into two parts, shown as Tables 2 and 3.

Then, apply Eq. (10) to calculate belief entropy of each BPA, which measures the uncertainty of the information. Compared to the existing work (Li et al. 2014), the mass assigned to the $\theta$ is not taken into consideration, because it represents the uncertainty. It isn't appropriate to identify the CSFs by $m(\theta)$. However, it doesn't mean that the mass of $\theta$ doesn't provide any information. So, the belief entropy is introduced in this paper, which is the formula for the $m(\theta)$. And the results are shown in Table 4. Thus, we substitute belief entropy into the new function (Eq. (15)) to get a new matrix whose the element can be a coefficient multiplied by BPA, shown in Table 5.

Multiply the $m(Y)$ with the corresponding reliability coefficient to obtain the direct relation matrix of influential factors, as the Table 6 shows.

Normalize the direct relation matrix as an iterative for DEMATEL analysis. The normalized direct relation matrix is shown in Table 7. Total relation matrix which contains direct and indirect relations among factors can be derived from Eq. (14). Table 8 shows the total relation between factors.

Thus, the sum of each row $R_i (i = 1, 2, \ldots, 10)$ and column $C_i (i = 1, 2, \ldots, 10)$ of the fused total relation matrices can be calculated. Thus, the value of $(R_i - C_i)$ can also be computed, as the Table 9 shows. As factors having higher values of $(R - C)$ have higher influence to another and are assumed to have higher priority, factors are classified into cause and effect category.

**Table 2** The raw data referenced in this paper (Li et al. 2014)

| | F1 | F2 | F3 | F4 | F5 |
|---|---|---|---|---|---|
| F1 | 0.0000 | (0.0009, 0.9989, 0.0002) | (0.0010, 0.9990, 0.0000) | (0.0077, 0.9914, 0.0009) | (0.0922, 0.9069, 0.0009) |
| F2 | (0.8788, 0.1155, 0.0057) | 0.0000 | (0.5059, 0.4917, 0.0024) | (0.3541, 0.6405, 0.0054) | (0.7404, 0.2510, 0.0087) |
| F3 | (0.3087, 0.6895, 0.0018) | (0.0666, 0.9308, 0.0027) | 0.0000 | (0.0244, 0.9734, 0.0022) | (0.2379, 0.7599, 0.0022) |
| F4 | (0.0621, 0.9338, 0.0041) | (0.0556, 0.9421, 0.0023) | (0.0024, 0.9976, 0.0000) | 0.0000 | (0.0930, 0.9031, 0.0039) |
| F5 | (0.2129, 0.7858, 0.0012) | (0.2889, 0.7067, 0.0044) | (0.9073, 0.0894, 0.0033) | (0.2188, 0.7813, 0.0000) | 0.0000 |
| F6 | (0.6469, 0.3510, 0.0021) | (0.6570, 0.3415, 0.0015) | (0.1454, 0.8512, 0.0035) | (0.1543, 0.8441, 0.0016) | (0.5441, 0.4529, 0.0030) |
| F7 | (0.6460, 0.3482, 0.0058) | (0.0164, 0.9825, 0.0012) | (0.2396, 0.7575, 0.0029) | (0.0007, 0.9993, 0.0000) | (0.0065, 0.9935, 0.0000) |
| F8 | (0.8418, 0.1563, 0.0019) | (0.1853, 0.8100, 0.0048) | (0.0923, 0.9032, 0.0045) | (0.0024, 0.9976, 0.0000) | (0.0026, 0.9974, 0.0000) |
| F9 | (0.1823, 0.8152, 0.0026) | (0.8710, 0.1290, 0.0000) | (0.4000, 0.6000, 0.0000) | (0.0055, 0.9925, 0.0020) | (0.0645, 0.9304, 0.0052) |
| F10 | (0.7063, 0.2916, 0.0021) | (0.2187, 0.7722, 0.0091) | (0.2821, 0.7151, 0.0028) | (0.0092, 0.9854, 0.0054) | (0.2215, 0.7697, 0.0087) |

**Table 3** The raw data referenced in this paper (Li et al. 2014)

| | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|
| F1 | (0.1050, 0.8932, 0.0018) | (0.6651, 0.3323, 0.0027) | (0.9978, 0.0017, 0.0005) | (0.0684, 0.9261, 0.0055) | (0.1726, 0.8233, 0.0041) |
| F2 | (0.8694, 0.1288, 0.0018) | (0.8068, 0.1887, 0.0045) | (0.4630, 0.5251, 0.0119) | (0.8555, 0.1416, 0.0029) | (0.1095, 0.8865, 0.0039) |
| F3 | (0.0762, 0.9219, 0.0019) | (0.0224, 0.9772, 0.0004) | (0.5994, 0.3970, 0.0036) | (0.4006, 0.5897, 0.0096) | (0.0536, 0.9435, 0.0030) |
| F4 | (0.0048, 0.9949, 0.0003) | (0.0148, 0.9840, 0.0011) | (0.1327, 0.8646, 0.0027) | (0.0299, 0.9641, 0.0060) | (0.0359, 0.9623, 0.0018) |
| F5 | (0.0317, 0.9676, 0.0007) | (0.0602, 0.9355, 0.0043) | (0.2060, 0.7909, 0.0031) | (0.5959, 0.3966, 0.0075) | (0.1986, 0.7945, 0.0068) |
| F6 | 0.0000 | (0.3647, 0.6324, 0.0029) | (0.3652, 0.6313, 0.0035) | (0.3262, 0.6713, 0.0025) | (0.4322, 0.5663, 0.0016) |
| F7 | (0.0292, 0.9693, 0.0015) | 0.0000 | (0.9538, 0.0409, 0.0053) | (0.0109, 0.9892, 0.0000) | (0.0387, 0.9584, 0.0029) |
| F8 | (0.3280, 0.6667, 0.0053) | (0.8110, 0.1664, 0.0227) | 0.0000 | (0.0554, 0.9271, 0.0175) | (0.5364, 0.4437, 0.0199) |
| F9 | (0.4057, 0.5755, 0.0189) | (0.9641, 0.0299, 0.0060) | (0.8725, 0.1175, 0.0100) | 0.0000 | (0.5281, 0.4607, 0.0112) |
| F10 | (0.3617, 0.6353, 0.0030) | (0.3052, 0.6936, 0.0012) | (0.9758, 0.0242, 0.0000) | (0.5665, 0.4234, 0.0101) | 0.0000 |

**Table 4** Belief entropy of each BPA

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.0000 | 0.0135 | 0.0114 | 0.0769 | 0.4555 | 0.5062 | 0.9468 | 0.0251 | 0.4173 | 0.7074 |
| F2 | 0.5750 | 0.0000 | 1.0256 | 0.9913 | 0.8949 | 0.5756 | 0.7461 | 1.0973 | 0.6210 | 0.5409 |
| F3 | 0.9126 | 0.3839 | 0.0000 | 0.1915 | 0.8167 | 0.4114 | 0.1604 | 1.0066 | 1.0576 | 0.3353 |
| F4 | 0.3803 | 0.3367 | 0.0243 | 0.0000 | 0.4889 | 0.0483 | 0.1254 | 0.5954 | 0.2561 | 0.2449 |
| F5 | 0.7620 | 0.9129 | 0.4712 | 0.7579 | 0.0000 | 0.2123 | 0.3747 | 0.7679 | 1.0390 | 0.7866 |
| F6 | 0.9587 | 0.9440 | 0.6364 | 0.6398 | 1.0252 | 0.0000 | 0.9778 | 0.9838 | 0.9387 | 1.0050 |
| F7 | 0.9895 | 0.1358 | 0.8264 | 0.0083 | 0.0566 | 0.2089 | 0.0000 | 0.3022 | 0.0866 | 0.2694 |
| F8 | 0.6478 | 0.7415 | 0.4922 | 0.0243 | 0.0261 | 0.9659 | 0.8356 | 0.0000 | 0.4624 | 1.1462 |
| F9 | 0.7144 | 0.5547 | 0.9710 | 0.0732 | 0.3996 | 1.1249 | 0.2561 | 0.6170 | 0.0000 | 1.0919 |
| F10 | 0.8948 | 0.8437 | 0.8892 | 0.1324 | 0.8457 | 0.9764 | 0.9022 | 0.1644 | 1.0724 | 0.0000 |

**Table 5** Matrix of reliability

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 1.0000 | 0.9867 | 0.9887 | 0.9286 | 0.6870 | 0.6639 | 0.5137 | 0.9755 | 0.7056 | 0.5857 |
| F2 | 0.6349 | 1.0000 | 0.4937 | 0.5022 | 0.5277 | 0.6347 | 0.5727 | 0.4768 | 0.6169 | 0.6490 |
| F3 | 0.5228 | 0.7226 | 1.0000 | 0.8393 | 0.5504 | 0.7085 | 0.8618 | 0.4984 | 0.4860 | 0.7489 |
| F4 | 0.7245 | 0.7481 | 0.9763 | 1.0000 | 0.6716 | 0.9539 | 0.8886 | 0.6268 | 0.7961 | 0.8033 |
| F5 | 0.5675 | 0.5228 | 0.6797 | 0.5689 | 1.0000 | 0.8249 | 0.7274 | 0.5656 | 0.4904 | 0.5597 |
| F6 | 0.5105 | 0.5144 | 0.6111 | 0.6098 | 0.4938 | 1.0000 | 0.5056 | 0.5041 | 0.5158 | 0.4988 |
| F7 | 0.5026 | 0.8804 | 0.5475 | 0.9918 | 0.9464 | 0.8272 | 1.0000 | 0.7679 | 0.9203 | 0.7878 |
| F8 | 0.6069 | 0.5742 | 0.6702 | 0.9763 | 0.9746 | 0.5087 | 0.5448 | 1.0000 | 0.6838 | 0.4659 |
| F9 | 0.5833 | 0.6432 | 0.5074 | 0.9318 | 0.7145 | 0.4706 | 0.7961 | 0.6184 | 1.0000 | 0.4780 |
| F10 | 0.5278 | 0.5424 | 0.5293 | 0.8831 | 0.5418 | 0.5060 | 0.5257 | 0.8588 | 0.4825 | 1.0000 |

**Table 6** Direct relation matrix of influential factors

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.0000 | 0.0009 | 0.0010 | 0.0072 | 0.0633 | 0.0697 | 0.3416 | 0.9734 | 0.0483 | 0.1011 |
| F2 | 0.5580 | 0.0000 | 0.2498 | 0.1778 | 0.3907 | 0.5518 | 0.4621 | 0.2208 | 0.5278 | 0.0711 |
| F3 | 0.1614 | 0.0481 | 0.0000 | 0.0205 | 0.1310 | 0.0540 | 0.0193 | 0.2987 | 0.1947 | 0.0401 |
| F4 | 0.0450 | 0.0416 | 0.0023 | 0.0000 | 0.0625 | 0.0046 | 0.0132 | 0.0832 | 0.0238 | 0.0288 |
| F5 | 0.1208 | 0.1510 | 0.6167 | 0.1245 | 0.0000 | 0.0261 | 0.0438 | 0.1165 | 0.2923 | 0.1112 |
| F6 | 0.3303 | 0.3380 | 0.0889 | 0.0941 | 0.2687 | 0.0000 | 0.1844 | 0.1841 | 0.1683 | 0.2156 |
| F7 | 0.3247 | 0.0144 | 0.1312 | 0.0007 | 0.0062 | 0.0242 | 0.0000 | 0.7325 | 0.0100 | 0.0305 |
| F8 | 0.5109 | 0.1064 | 0.0619 | 0.0023 | 0.0025 | 0.1668 | 0.4418 | 0.0000 | 0.0379 | 0.2499 |
| F9 | 0.1063 | 0.5602 | 0.2029 | 0.0051 | 0.0461 | 0.1909 | 0.7675 | 0.5396 | 0.0000 | 0.2524 |
| F10 | 0.3728 | 0.1186 | 0.1493 | 0.0081 | 0.1200 | 0.1830 | 0.1604 | 0.8380 | 0.2734 | 0.0000 |

Finally, five factors are identified as CSFs in emergency management. These CSFs ranked by the degree of importance are $F_2 > F_9 > F_{10} > F_6 > F_5$.

## 5 Results and discussions

In this paper, an improved evidential DEMATEL method is proposed, which defines a reliability function in the decision process. The reliability function satisfies two conditions. One is reliability decreases with the increase of information uncertainty. The other is the value of the reliability varies between zero and one, which can be used as a weight value to correct previous data. In the calculation of the reliability function, belief entropy is used to measure the uncertainty of information. Because of the advantages of the belief entropy used, the quality of the complete set allocated in BPA also has an impact, which was completely ignored in the previous work (Li et al. 2014).

In order to illustrate the impact of the introduction of belief entropy, a further analysis on the superiority and

**Table 7** Normalized direct relation matrix

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.0000 | 0.0003 | 0.0003 | 0.0022 | 0.0197 | 0.0217 | 0.1064 | 0.3033 | 0.0150 | 0.0315 |
| F2 | 0.1738 | 0.0000 | 0.0778 | 0.0554 | 0.1217 | 0.1719 | 0.1440 | 0.0688 | 0.1644 | 0.0221 |
| F3 | 0.0503 | 0.0150 | 0.0000 | 0.0064 | 0.0408 | 0.0168 | 0.0060 | 0.0931 | 0.0607 | 0.0125 |
| F4 | 0.0140 | 0.0130 | 0.0007 | 0.0000 | 0.0195 | 0.0014 | 0.0041 | 0.0259 | 0.0074 | 0.0090 |
| F5 | 0.0376 | 0.0471 | 0.1921 | 0.0388 | 0.0000 | 0.0081 | 0.0136 | 0.0363 | 0.0911 | 0.0346 |
| F6 | 0.1029 | 0.1053 | 0.0277 | 0.0293 | 0.0837 | 0.0000 | 0.0574 | 0.0574 | 0.0524 | 0.0672 |
| F7 | 0.1012 | 0.0045 | 0.0409 | 0.0002 | 0.0019 | 0.0075 | 0.0000 | 0.2282 | 0.0031 | 0.0095 |
| F8 | 0.1592 | 0.0332 | 0.0193 | 0.0007 | 0.0008 | 0.0520 | 0.1377 | 0.0000 | 0.0118 | 0.0779 |
| F9 | 0.0331 | 0.1745 | 0.0632 | 0.0016 | 0.0144 | 0.0595 | 0.2391 | 0.1681 | 0.0000 | 0.0787 |
| F10 | 0.1161 | 0.0370 | 0.0465 | 0.0025 | 0.0374 | 0.0570 | 0.0500 | 0.2611 | 0.0852 | 0.0000 |

**Table 8** Total relation matrix

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|---|---|---|---|---|---|---|---|---|---|---|
| F1 | 0.1139 | 0.0347 | 0.0347 | 0.0085 | 0.0373 | 0.0617 | 0.2005 | 0.4225 | 0.0437 | 0.0800 |
| F2 | 0.3426 | 0.0967 | 0.1668 | 0.0776 | 0.1773 | 0.2421 | 0.3244 | 0.3603 | 0.2397 | 0.1102 |
| F3 | 0.1112 | 0.0460 | 0.0299 | 0.0133 | 0.0571 | 0.0457 | 0.0757 | 0.1810 | 0.0855 | 0.0441 |
| F4 | 0.0340 | 0.0211 | 0.0115 | 0.0027 | 0.0252 | 0.0112 | 0.0242 | 0.0535 | 0.0172 | 0.0181 |
| F5 | 0.1234 | 0.0910 | 0.2268 | 0.0489 | 0.0332 | 0.0527 | 0.1050 | 0.1727 | 0.1364 | 0.0737 |
| F6 | 0.2189 | 0.1525 | 0.0894 | 0.0461 | 0.1228 | 0.0609 | 0.1750 | 0.2413 | 0.1143 | 0.1167 |
| F7 | 0.1808 | 0.0281 | 0.0611 | 0.0048 | 0.0174 | 0.0395 | 0.0801 | 0.3290 | 0.0261 | 0.0483 |
| F8 | 0.2499 | 0.0649 | 0.0536 | 0.0096 | 0.0291 | 0.0903 | 0.2220 | 0.1808 | 0.0496 | 0.1151 |
| F9 | 0.2241 | 0.2312 | 0.1355 | 0.0237 | 0.0728 | 0.1450 | 0.3912 | 0.4179 | 0.0827 | 0.1478 |
| F10 | 0.2578 | 0.0969 | 0.1003 | 0.0162 | 0.0739 | 0.1186 | 0.1980 | 0.4515 | 0.1360 | 0.0699 |

**Table 9** The analysis of the total relation matrix

| Order | R | Order | C | Order | R + C | Order | R − C |
|---|---|---|---|---|---|---|---|
| F2 | 2.1376 | F8 | 2.8104 | F8 | 3.8752 | F2 | 1.2745 |
| F9 | 1.8719 | F1 | 1.8567 | F2 | 3.0008 | F9 | 0.9407 |
| F10 | 1.5192 | F7 | 1.7961 | F1 | 2.8942 | F10 | 0.6952 |
| F6 | 1.3377 | F9 | 0.9312 | F9 | 2.8032 | F6 | 0.4701 |
| F8 | 1.0648 | F3 | 0.9094 | F7 | 2.6113 | F5 | 0.4177 |
| F5 | 1.0637 | F6 | 0.8676 | F10 | 2.3431 | F4 | -0.0326 |
| F1 | 1.0375 | F2 | 0.8631 | F6 | 2.2054 | F3 | -0.2198 |
| F7 | 0.8152 | F10 | 0.8239 | F5 | 1.7098 | F1 | -0.8192 |
| F3 | 0.6896 | F5 | 0.6461 | F3 | 1.5990 | F7 | -0.9809 |
| F4 | 0.2188 | F4 | 0.2514 | F4 | 0.4703 | F8 | -1.7456 |

rationality of the proposed method and a comparison with previous studies are shown in this section.

## 5.1 Superiority of the proposed method

Reviewing the existing research on the emergency management, most of them are aimed at a specific measure to optimize (Goodwin et al. 2015; Radianti et al. 2015) but ignore the reason why they choose this factor. Due to the fact that emergency management covers various areas, it is necessary to solve the optimization problem from an overall perspective. The proposed method shows different factors of different fields and identifies the CSFs by considering the interrelationship between them. The thought of optimizing the management from a higher viewpoint can also be applied to other systems.

According to the evidential DEMATEL (Li et al. 2014) and D-DEMATEL (Zhou et al. 2017), the previous work doesn't take the uncertainty of the information itself into account. In the evidential DEMATEL, it completely ignores the mass assigned to the universal set. As for D-DEMATEL, it directly makes the mass of each element the same 0.5.

**Table 10** The cause–effect classification and importance ranking of factors

| Category | Evidential DEMATEL | $R-C$ | D-DEMATEL | $R-C$ | The proposed method | $R-C$ |
|---|---|---|---|---|---|---|
| Cause | F2 | 1.1853 | F2 | 1.0035 | F2 | 1.2745 |
| | F10 | 0.7140 | F9 | 0.6010 | F9 | 0.9407 |
| | F9 | 0.5795 | F6 | 0.5833 | F10 | 0.6952 |
| | F6 | 0.5273 | F10 | 0.4851 | F6 | 0.4701 |
| | F5 | 0.3529 | F5 | 0.4344 | F5 | 0.4177 |
| | – | – | F4 | 0.0751 | – | – |
| Effect | F4 | − 0.0824 | F3 | −0.1214 | F4 | − 0.0326 |
| | F3 | − 0.1884 | F7 | − 0.8832 | F3 | − 0.2198 |
| | F7 | − 0.9704 | F1 | − 0.9111 | F1 | − 0.8192 |
| | F1 | − 1.0101 | F8 | − 1.2668 | F7 | − 0.9809 |
| | F8 | − 1.1077 | – | – | F8 | − 1.7456 |

They both think all of these information have the same influence on the final result. However, it isn't reasonable.

In this paper, the proposed method makes improvements on the basis of the evidential DEMATEL by introducing belief entropy to measure uncertainty. The explanation given in evidential DEMATEL is that the quality of the universal set expresses uncertainty and it is not appropriate to use $m(\theta)$ to identify CSFs. Although the mass assigned to the universal set represents that this part of the mass is what people don't know how to distribute, it does provide some information.

If the mass assigned to the universal set isn't taken into account, the mass comes from two aspects will be ignored. First, $m(\theta)$ expresses the ambiguity and uncertainty of language assessment when the linguistic assessments transformed into IFNs and BPAs. If we don't take $m(\theta)$ into account, the advantage of using intuitionistic fuzzy numbers will decrease. Second, $m(\theta)$ also comes from the step of normalizing the orthogonal sum (Eqs. (5) and (6)) obtained from combining. When we discard the quality of the empty set in the steps of combination, the quality allocated to other sets will be magnified, including the universal set.

Observing the calculation formula of belief entropy, we can see the mass assigned to universal set is used in the process of calculating belief entropy. That's why we introduce belief entropy in this paper. It is a good measure of uncertainty of the information itself, which means it expresses the experts' inexact language assessment better. In this way, the greater the value of uncertainty is, the smaller the impact of this information on the final result is.

### 5.2 Rationality of the result

Table 10 which represents the comparison between the previous works and this paper is produced.

As the result shows, the CSFs identified by the proposed method is F2, F9, F10, F6, F5, which is same as evidential DEMATEL and F4 less than D-DEMATEL. That means its results are reliable to a certain extent. But the order of the CSFs has some differences. Based on what are analyzed above, these differences are a reflection of the more reasonable result.

Apart from the difference of the order, the difference value of the improved evidential DEMATEL between the maximum and the minimum is the biggest. The greater the difference value is, the better the division between each factor is.

To sum up, the improved evidential DEMATEL solves the emergency management optimization problem from a overall perspective, which gives the reason why some specific measures could be chosen to optimize. Compared with the evidential DEMATEL and D-DEMATEL, the improved evidential DEMATEL is well addressed the uncertainty of the information by introducing the belief entropy. Therefore, the improved evidential DEMATEL is more reasonable than the previous work.

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