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A Study of an Extended DEMATEL Model of Critical Success Factors for Emergency Management

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Abstract

Under sudden natural disasters, scientific and effective emergency management is of great significance to disaster prevention and control. Identifying the critical success factors (CSFs) of emergency management can greatly improve emergency response efficiency. This paper proposes a DEMATEL method based on bipolar fuzzy number (BFN), establishes evaluating direct influencing matrices, and transforms them into a total influencing matrix of precise values. Through the DEMATEL method, the prominence degree and the relation degree are sorted. Finally, an example is used to verify the effectiveness of the method.

Keywords

Emergency management; Bipolar fuzzy number; The DEMATEL method.

1. Introduction

Since the consequences of emergencies are often catastrophic, in recent years, the competent government departments have attached great importance to the emergency management. In order to improve and optimize the ability to deal with emergencies, experts and scholars have conducted a series of related studies on emergency management. For example, Garrido and Aguirre[1] proposed a modeling framework to prove the importance of emergency logistics for improving the social impact of large earthquakes. Zahedi et al.[2] proposed a multi-objective decision-making model to solve the problem of cargo distribution planning and vehicle routing in emergency situations. Chen et al.[3] proposed a decision model and group decision support system for emergency management and urban response. Although the above studies considered improving some aspects of emergency management, they neglected to improve the overall efficiency of the system. Identifying the critical success factors (CSFs) of emergency management and focusing on improving them is an effective method.

The decision making trial and evaluation laboratory (DEMATEL) method[4,5] is an effective approach to distinguish the group relationship in the system. By calculating the attribute values of every factor, the importance of each factor in the system is judged, and the CSFs can be identified. At present, the DEMATEL method has received attention in emergency management. Inspired by belief entropy, Shang et al.[6] defined a new function for calculating information reliability, and use the DEMATEL method to find out the five key success factors of emergency management. Ju et al.[7] proposed a new framework that combines ANP method, DEMATEL technology, and binary array solutions to solve the problem of urban fire emergency plan selection. Li et al.[8] proposed a new DEMATEL method to identify critical success factors. This method transforms the evaluation of influencing factors in the form of intuitionistic fuzzy numbers into basic probability assignments. Then the Dempster-Shafer theory was applied to combinatorial decision-making, and finally five CSFs were found.

In view of these, this paper constructs the DEMATEL algorithm based on the bipolar fuzzy number (BFN) to realize the classification and sorting of the influencing factors of emergency management,

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which is conducive to the rational allocation of resources in the emergency management of emergencies and improves the efficiency of emergency response.

2. Basic Elements of a Bipolar Fuzzy Set

Definition 1[9]. Let $X=\{x_1,x_2,...,x_n\}$ be a fix set, $x\in X$. The positive membership function and the negative membership function of X are expressed as $u_A^+(x)$ and $v_A^-(x)$, which meet the conditions that $u_A^+(x):X\to[0,1]$ and $v_A^-(x):X\to[-1,0]$. Then, a bipolar fuzzy set (BFS) in X can be expressed as:

$$A=\{\langle x,u_A^+(x),v_A^-(x)\rangle \mid x\in X\}, \tag{1}$$

and $a=(u^+,v^-)$ is a bipolar fuzzy number (BFN).

Definition 2[10]. Based on basic operations of $a=(u^+,v^-)$, Wei et al. extend BFNs with Hamacher t-norm and t-conorm. Suppose $\gamma>0$ and $\lambda>0$, the operation rules of a_1 and a_2 are shown below:

$$(1)\ a_1\oplus a_2=\left(\frac{u_1^++u_2^+-u_1^+u_2^+-(1-\gamma)u_1^+u_2^+}{1-(1-\gamma)u_1^+u_2^+},\frac{-v_1^-v_2^-}{\gamma+(1-\gamma)(v_1^-+v_2^--v_1^-v_2^-)}\right);$$

$$(2)\ a_1\otimes a_2=\left(\frac{u_1^-u_2^-}{\gamma+(1-\gamma)(u_1^-+u_2^--u_1^-u_2^-)},\frac{v_1^-+v_2^--v_1^-v_2^--(1-\gamma)v_1^-v_2^-}{1-(1-\gamma)v_1^-v_2^-}\right);$$

$$(3)\ \lambda a=\left(\frac{(1+(\gamma-1)u^+)^\lambda-(1-u^+)^\lambda}{(1+(\gamma-1)u^+)^\lambda+(\gamma-1)(1-u^+)^\lambda},\frac{-\gamma\left|v^-\right|^\lambda}{(1+(\gamma-1)(1+v^-))^\lambda+(\lambda-1)\left|v^-\right|^\lambda}\right);$$

$$(4)\ a^\lambda=\left(\frac{\gamma(u^+)^\lambda}{(1+(\gamma-1)(1-u^+))^\lambda+(\gamma-1)(u^+)^\lambda},\frac{(1+(\gamma-1)\left|v^-\right|)^\lambda-(1+v^-)^\lambda}{(1+(\gamma-1)\left|v^-\right|)^\lambda+(\gamma-1)(1+v^-)^\lambda}\right).$$

Definition 3. The score function $S(a)$ and the accuracy function $A(a)$ of $a=(u^+,v^-)$ are evaluated as:

$$S(a)=(1+u^++v^-)/2,\quad S(a)\in[0,1], \tag{2}$$

$$A(a)=(u^+-v^-)/2,\quad A(a)\in[0,1]. \tag{3}$$

Definition 4[10]. The bipolar fuzzy Hamacher weighted average (BFHWA) operator of BFNs is defined as:

$$BFHWA_w(a_1,a_2,...,a_n)=\overset{n}{\underset{i=1}{\oplus}}(w_ia_i)=\left(\frac{\prod_{i=1}^n\left(1+(\gamma-1)u_i^+\right)^{w_i}-\prod_{i=1}^n(1-u_i^+)^{w_i}}{\prod_{i=1}^n\left(1+(\gamma-1)u_i^+\right)^{w_i}+(\gamma-1)\prod_{i=1}^n(1-u_i^+)^{w_i}},-\frac{\gamma\prod_{i=1}^n\left|v_i^-\right|^{w_i}}{\prod_{i=1}^n\left(1+(\gamma-1)(1+v_i^-)\right)^{w_i}+(\gamma-1)\prod_{i=1}^n\left|v_i^-\right|^{w_i}}\right). \tag{4}$$

3. The Proposed Approach

A modified DEMATEL approach based on BFNs (BFN-DEMATEL approach), which is used to identify CSFs is proposed in this section.

Table 1 The corresponding relations between linguistic variables and the values u^+, v^- of BFN

Linguistic description	u+	v-
Extremely low influence	0	0
Low influence	0.1	-0.1
A little lower influence	0.2	-0.2
Medium	0.3	-0.3
A little higher influence	0.4	-0.4
High influence	0.5	-0.5
Extremely high influence	0.6	-0.6

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$F=\{f_1, f_2,..., f_n\}$ is a set of influencing factors, and $E=\{e_1,e_2,...,e_t\}$ is a set of experts. The evaluating direct influencing matrices $A'^k=\left[a'^k_{ij}\right]_{n\times n}=\left[u^+(a'^k_{ij}),v^-(a'^k_{ij})\right]_{n\times n}$ $(k=1,2,...,t$; $i, j=1,2,...,n)$ are given by t experts, respectively. The value u^+ (the effect of f_i to f_j) and v^- (the effect of f_j to f_i) corresponding to the evaluation linguistic given by expert e_k to describe the influence relationship between f_i and f_j are given, see Table 1. If $i=j$, then $a'^k_{ij}=[0,0]$.

The steps of the BFN-DEMATEL approach are listed as follows:

Step 1. Suppose the experts have equal weights, $W=\{w_1=w_2=...=w_t\}$. Then the group direct influencing matrix $A'=\left[a'_{ij}\right]_{n\times n}=\left[u^+(a'_{ij}),v^-(a'_{ij})\right]_{n\times n}$ can be obtained by:

$$a'_{ij}=BFHWA(a'^1_{ij},a'^2_{ij},...,a'^t_{ij})=\left(\frac{\prod_{i=1}^{n}\left(1+(\gamma-1)u^+(a'^k_{ij})\right)^{w_k}-\prod_{i=1}^{n}(1-u^+(a'^k_{ij}))^{w_k}}{\prod_{i=1}^{n}\left(1+(\gamma-1)u^+(a'^k_{ij})\right)^{w_k}+(\gamma-1)\prod_{i=1}^{n}(1-u^+(a'^k_{ij}))^{w_k}},-\frac{\gamma\prod_{i=1}^{n}\left|v^-(a'^k_{ij})\right|^{w_k}}{\prod_{i=1}^{n}\left(1+(\gamma-1)(1+v^-(a'^k_{ij}))\right)^{w_k}+(\gamma-1)\prod_{i=1}^{n}\left|v^-(a'^k_{ij})\right|^{w_k}}\right), \quad (5)$$

$$\left(k=1,2,...,t;\gamma>0\right).$$

Step 2. Convert the group direct influencing matrix $A'=\left[a'_{ij}\right]_{n\times n}$ into the crisp direct influencing matrix $A=\left[a_{ij}\right]_{n\times n}$ by using the score function $S(a)$ of BFN:

$$a_{ij}=S(a'_{ij})=\frac{(1+u^+(a'_{ij})+v^-(a'_{ij}))}{2}. \quad (6)$$

Step 3. Normalize $A=\left[a_{ij}\right]_{n\times n}$ to $Y=\left[y_{ij}\right]_{n\times n}$ by:

$$Y=\frac{A}{\max\left(\max_{1\le i\le n}\sum_{j=1}^{n}a_{ij},\max_{1\le j\le n}\sum_{i=1}^{n}a_{ij}\right)}, \quad (7)$$

Step 4. Calculate the total influencing matrix $T=\left[t_{ij}\right]_{n\times n}$.

$$T=\lim_{e\to\infty}\left(Y+Y^2+...+Y^e\right)=Y(I-Y)^{-1}, \quad (8)$$

Step 5. Calculate the influential impact degree P_i and the influenced impact degree Q_j by Eq.(9-10).

$$P_i=\left[\sum_{j=1}^{n}y_{ij}\right]_{n\times 1}, \quad (9)$$

$$Q_j=\left[\sum_{i=1}^{n}y_{ij}\right]^T_{1\times n}. \quad (10)$$

Then, the prominence degree P_i+Q_i and the relation degree P_i-Q_i of f_i can be obtained.

Based on the value of P_i , Q_j , P_i+Q_i and P_i-Q_i , CSFs can be identified.

4. Illustrative Example

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In this section, taking the Jiuzhaigou Earthquake in 2017 as an example, the BFN-DEMATEL method is used to identify CSFs in emergency management.

There are twelve influencing factors of emergency management $F=\{f_1, f_2,..., f_{12}\}$ which selected from the existing literature[11], see Table 2. Five experts $E=\{e_1,e_2,e_3,e_4,e_5\}$ engaged in emergency management research were invited to give their evaluating direct influencing matrices of the twelve factors by BFNs. Take the BFN-evaluating direct influencing matrix given by the first expert $A'^1=\left[a'^1_{ij}\right]_{12\times 12}$ as an example, see Table 3.

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Table 2 Influencing Factors of Emergency Management

Factor	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	Financial safeguards and prior planning of logistic centers and shelters
f5	Education campaign on disaster prevention and response
f6	Specific training of professionals such as rescue workers and medical staff
f7	Strong ability to send out specific early warning about potential hazards
f8	Very short response time to start the emergency plan
f9	Government unity of leadership to plan and coordinate as a whole
f10	The involvement and support of army
f11	The security of relief aids during distribution and transportation
f12	Effective emergency information system to ensure information transferring

Table 3 The Evaluating Direct Influencing Matrix of the First Expert

	f1	f2	f3	f4	...	f12
f1	[0,0]	[0.4,-0.2]	[0.4,-0.2]	[0.3,-0.3]	...	[0.3,-0.3]
f2	[0.2,-0.4]	[0,0]	[0.5,-0.1]	[0.2,-0.4]	...	[0.1,-0.5]
f3	[0.2,-0.4]	[0.1,-0.5]	[0,0]	[0.2,-0.4]	...	[0.1,-0.5]
f4	[0.3,-0.3]	[0.4,-0.2]	[0.4,-0.2]	[0,0]	...	[0.4,-0.2]
f5	[0.1,-0.5]	[0.4,-0.2]	[0.3,-0.3]	[0.1,-0.5]	...	[0.1,-0.5]
f6	[0.3,-0.3]	[0.5,-0.1]	[0.4,-0.2]	[0.3,-0.3]	...	[0.4,-0.2]
f7	[0.3,-0.3]	[0.5,-0.1]	[0.4,-0.2]	[0.3,-0.3]	...	[0.3,-0.3]
f8	[0.2,-0.4]	[0.4,-0.2]	[0.3,-0.3]	[0.3,-0.3]	...	[0.1,-0.5]
f9	[0.2,-0.4]	[0.4,-0.2]	[0.4,-0.2]	[0.2,-0.4]	...	[0.3,-0.3]
f10	[0.3,-0.3]	[0.5,-0.1]	[0.5,-0.1]	[0.4,-0.2]	...	[0.3,-0.3]
f11	[0.1,-0.5]	[0.4,-0.2]	[0.4,-0.2]	[0.2,-0.4]	...	[0.2,-0.4]
f12	[0.3,-0.3]	[0.5,-0.1]	[0.5,-0.1]	[0.2,-0.4]	...	[0,0]

The next steps of the BFN-DEMATEL approach can be listed as follows:

Step 1. Suppose $\gamma = 2$, then the group direct influencing matrix $A' = \left[a'_{ij}\right]_{12\times12}$ can be calculated by Eq.(5), and the results see Table 4.

Table 4 The Results of the Group Direct Influencing Matrix

	f1	f2	f3	...	f12
f1	[0,0]	[0.384,-0.231]	[0.361,-0.236]		[0.280,-0318]
f2	[0.242,-0.368]	[0,0]	[0.285,-0.292]		[0.201,-0.434]
f3	[0.241,-0.357]	[0.324,-0.264]	[0,0]		[0.221,-0.396]
f4	[0.300,-0.300]	[0.364,-0.220]	[0.361,-0.236]		[0.341,-0.256]
f5	[0.184,-0.420]	[0.282,-0.312]	[0.202,-0.374]		[0.160,-0.476]
f6	[0.262,-0.331]	[0.344,-0.209]	[0.223,-0.347]		[0.262,-0.347]
f7	[0.366,-0.272]	[0.386,-0.190]	[0.364,-0.264]		[0.301,-0.294]
f8	[0.285,-0.347]	[0.323,-0.266]	[0.262,-0.331]		[0.181,-0.397]
f9	[0.282,-0.357]	[0.441,-0.200]	[0.346,-0.231]		[0.280,-0.318]
f10	[0.282,-0.357]	[0.386,-0.220]	[0.325,-0.254]		[0.221,-0.374]
f11	[0.266,-0.438]	[0.323,-0.289]	[0.284,-0.328]		[0.262,-0.385]
f12	[0.321,-0.277]	[0.443,-0.190]	[0.402,-0.207]		[0,0]

Step 2. The corresponding crisp influencing matrix $A = \left[a_{ij}\right]_{12\times12}$ is calculated by Eq. (6) on the basis of $A' = \left[a'_{ij}\right]_{12\times12}$, and the results see Table 5.

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Table 5 The Crisp Direct Influencing Matrix

	f1	f2	f3	f4	f5	...	f12
f1	0.5	0.576	0.563	0.5	0.725	...	0.481
f2	0.437	0.5	0.497	0.448	0.525	...	0.383
f3	0.442	0.530	0.5	0.442	0.691	...	0.413
f4	0.5	0.572	0.563	0.5	0.628	...	0.543
f5	0.382	0.485	0.414	0.385	0.5	...	0.342
f6	0.466	0.568	0.438	0.456	0.558	...	0.457
f7	0.547	0.598	0.550	0.547	0.655	...	0.504
f8	0.469	0.528	0.466	0.476	0.552	...	0.392
f9	0.462	0.621	0.558	0.525	0.640	...	0.481
f10	0.462	0.583	0.536	0.468	0.626	...	0.423
f11	0.414	0.517	0.478	0.452	0.572	...	0.438
f12	0.522	0.627	0.598	0.462	0.666	...	0.5

Step 3. $A=\left[a_{ij}\right]_{12\times 12}$ can be normalized by Eq. (7), and the normalized influencing matrix $Y=\left[y_{ij}\right]_{12\times 12}$ see Table 6.

Table 6 The Normalized Influencing Matrix

	f1	f2	f3	f4	f5	...	f12
f1	0.068	0.079	0.077	0.068	0.099	...	0.066
f2	0.060	0.068	0.068	0.061	0.072	...	0.052
f3	0.060	0.072	0.068	0.060	0.094	...	0.056
f4	0.068	0.078	0.077	0.068	0.086	...	0.074
f5	0.052	0.066	0.056	0.052	0.068	...	0.047
f6	0.063	0.077	0.060	0.062	0.076	...	0.062
f7	0.075	0.081	0.075	0.075	0.089	...	0.069
f8	0.064	0.072	0.063	0.065	0.075	...	0.053
f9	0.063	0.085	0.076	0.072	0.087	...	0.066
f10	0.063	0.079	0.073	0.064	0.085	...	0.058
f11	0.056	0.071	0.065	0.062	0.078	...	0.060
f12	0.071	0.085	0.081	0.063	0.091	...	0.068

Step 4. The total influencing matrix $T=\left[t_{ij}\right]_{12\times 12}$ obtained by Eq. (8) see Table 7.

Table 7 The Total Influencing Matrix

	f1	f2	f3	f4	f5	...	f12
f1	0.391	0.466	0.432	0.395	0.522	...	0.374
f2	0.326	0.387	0.360	0.330	0.420	...	0.306
f3	0.360	0.431	0.397	0.363	0.486	...	0.342
f4	0.386	0.459	0.426	0.389	0.502	...	0.377
f5	0.298	0.361	0.326	0.301	0.390	...	0.281
f6	0.353	0.424	0.378	0.355	0.455	...	0.339
f7	0.409	0.483	0.443	0.413	0.528	...	0.388
f8	0.351	0.416	0.379	0.356	0.451	...	0.328
f9	0.383	0.468	0.427	0.395	0.506	...	0.371
f10	0.364	0.440	0.404	0.368	0.479	...	0.345
f11	0.329	0.397	0.364	0.337	0.435	...	0.320
f12	0.402	0.482	0.445	0.398	0.524	...	0.384

Step 5. The influential impact degree P_i and the influenced impact degree Q_j of f_i $(i=1,2,\ldots,12)$ can be calculated by Eq.(9-10). And the prominence degree P_i+Q_i and the relation degree P_i-Q_i are also easy to figure out, see Table 8.

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Besides, the influence diagram of factors determined according to $P_i + Q_i$ and $P_i - Q_i$ is obtained, see Fig. 1.

Table 8 Related Values for Each Factor

	P_i	Q_i	$P_i + Q_i$	$P_i - Q_i$
f1	5.1241	4.3520	9.4761	0.7720
f2	4.2156	5.2139	9.4295	-0.9983
f3	4.7492	4.7802	9.5294	-0.0310
f4	5.0323	4.4012	9.4335	0.6311
f5	3.8993	5.6978	9.5971	-1.7985
f6	4.5887	4.8997	9.4884	-0.3111
f7	5.3037	4.1530	9.4567	1.1506
f8	4.5521	4.9690	9.5211	-0.4169
f9	5.0679	4.3684	9.4363	0.6995
f10	4.7710	4.6988	9.4698	0.0721
f11	4.3173	5.1791	9.4964	-0.8618
f12	5.2460	4.1537	9.3996	1.0923

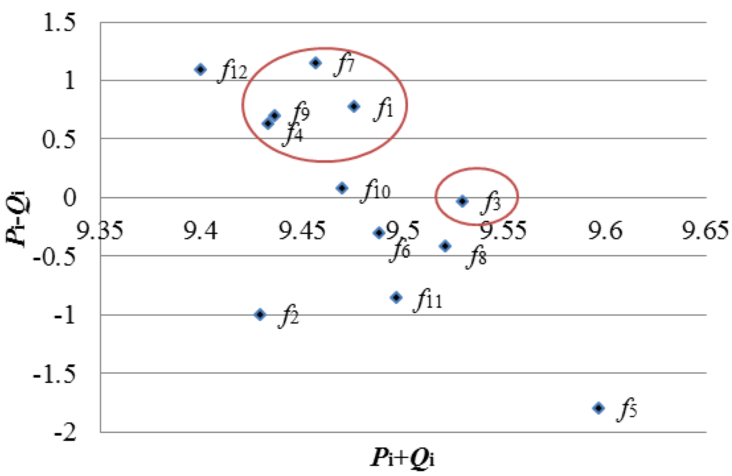

Fig. 1 The Cause-effect Relationship Diagram

5. Discussion of the Results

According to Table 8, it can be seen that the order of the prominence degree $P_i + Q_i$ is: $f_5 > f_3 > f_8 > f_{11} > f_6 > f_1 > f_{10} > f_7 > f_9 > f_4 > f_2 > f_{12}$; and the order of the relation degree $P_i - Q_i$ is: $f_7 > f_{12} > f_1 > f_9 > f_4 > f_{10} > f_3 > f_6 > f_8 > f_{11} > f_2 > f_5$. Among them, according to the positive and negative conditions of $P_i - Q_i$, f_7, f_{12}, f_1, f_9, f_4 and f_{10} with a score greater than 0 are defined as cause factors, which have an impact on the entire system, while f_3, f_6, f_8, f_{11}, f_2 and f_5 are effect factors, which affected by the entire system.The CSFs in emergency management can be identified combined with Tab. 8 and Fig. 1.

5.1 Cause Factors Analysis

Among all factors in cause group, the factor f_7 has the largest value of $P_i - Q_i$, which is obviously the factor that has the greatest impact on the system. Its value of P_i also ranks first in the system. Although the $P_i + Q_i$ value of f_7 is not ranked high, the gap between the values is very small. Therefore, consider f_7 as a CSF.

Similarly, the factors f_1, f_4 and f_9 all have relatively high values of $P_i - Q_i$ and P_i among the twelve factors, which indicate that, the factors play important role in the system. Besides, the $P_i + Q_i$ values of them are acceptable, though the values are not significant. The three factors can also be regarded as CSFs.

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Apparently, the factor f_{12} has a great impact on the entire system, but unfortunately, the P_i+Q_i value of f_{12} is not high enough, it can not be considered as a CSF. All indicators of f_{10} are at a low level, therefore, it have little ability to impact on the system, it can not be regarded as CSFs.

5.2 Effect Factors Analysis

Though classified as net effect factor, the factor f_3 have very high value of P_i+Q_i, which indicates that this factor is significant to the operation of the emergency management system. And, since its value of P_i-Q_i is only slightly less than 0, it is less susceptible. Consequently, f_3 can be regarded as a CSF.

f_5 has the largest value of P_i+Q_i, but it also has the lowest value of P_i-Q_i, which makes the factor unstable. As for other factors in this system, because the numerical characteristics are not obvious, they can not be considered as CSFs.

6. Conclusion

This paper proposes a BFN-DEMATEL method for the CSFs of emergency management. Through optimizing expert evaluation, the 5 CSFs in the system are identified. From the results in the study, "well-planned emergency relief supply system", "applicable emergency response plan and regulations", "financial safeguards and prior planning of logistic centers and shelters", "strong ability to send out specific early warning about potential hazards" and "Government unity of leadership to plan and coordinate as a whole" these five factors are critical in the emergency management system. By improving these CSFs, the efficiency of the entire emergency management can be greatly improved. This method is more practical and universal, and can also be applied to other complex fields.

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