Journal of Organizational and End User Computing
Volume 34 • Issue 7

Maximum-Entropy-Based Decision-Making Trial and Evaluation Laboratory and Its Application in Emergency Management

Yuelin Che, University of Electronic Science and Technology of China, China
Yong Deng, University of Electronic Science and Technology of China, China
Yu-Hsi Yuan, Chinese Culture University, Taiwan

ABSTRACT

Decision-making trial and evaluation laboratory (DEMATEL) can visualize the structure of complex causal relationships, so it is widely used in decision making. One of the important steps in DEMATEL is normalization, and it has received much attention in recent years. Maximum entropy (MaxEnt) is a universal principle, and it is an effective tool for determining the amount of information existed in evidence. In this paper, the authors propose MaxEnt-based DEMATEL. The greatest contribution in this paper is the use of MaxEnt principle to determine the normalized direct influence matrix, which allows to obtain the normalized matrix with minimal information loss. The authors illustrate emergency management to show the superiority of the proposed method.

KEYWORDS

Decision Optimization, DEMATEL, Effective Tool, Emergency Management, Information Volume, Maximum Entropy, Normalization, Uncertainty

INTRODUCTION

Decision-making trial and evaluation laboratory (DEMATEL) technique was first developed by the Geneva Research Centre of the Battelle Memorial Institute (Gabus & Fontela, 1972) to solve complex problems such as conflicting evidence (Zhang & Deng, 2019) and supplier selection (Liu et al., 2018). There are a number of approaches that can be adopted in order to make rational decisions, such as DEMATEL, AHP hierarchy process (Saaty, 1980), and technique for order preference by similarity to an ideal solution (known as TOPSIS) (Zavadskas et al., 2016). Among the above methods, DEMATEL has been widely used because of its large data capacity. DEMATEL is an effective method which analyzes the interrelationships between system factors and visualizes this structure through cause-effect relationship maps. It has been widely used in various areas (Altuntas & Gok, 2021; Büyüközkan & Güleryüz, 2016) and can be extended by other theories and approaches, such as grey decision making trial (Bai & Sarkis, 2013), analytic network process (Wu, 2008), and fuzzy numbers (Wu &d Lee, 2007). Until now, DEMATEL has been extended to make better decisions in different situations.

One of the important steps in DEMATEL is to normalize the direction influence matrix.Many typical DEMATEL methods exist. However, to the best of the authors' knowledge, no normalized method from the perspective of maximum entropy (MaxEnt) in DEMATEL is available. From the informational perspective, it can be found that these existing normalized methods actually obtain

DOI: 10.4018/JOEUC.302891

different probabilities whose values are ranged from 0 to 1. Especially with regard to the row-sum normalized method, it obtains a probability distribution.

From a novel perspective of information theory, in this paper the authors propose DEMATEL based on MaxEnt, named as MaxEnt-DEMETEL. In information theory, entropy is used to measure the amount of information; the more uncertain the system is, the greater its entropy. MaxEnt is an effective tool for determining the amount of information existed in evidence. The proposed method applies the MaxEnt principle to the second normalized step of DEMATEL. Specifically, a novel normalized method is proposed in the MaxEnt-DEMATEL method. The process can be divided into three steps. Firstly, experts evaluate the direct relations of influential factors in emergency management. Evaluation results are presented in the form of intuitionistic fuzzy number (IFN). Secondly, the proposed method applies the MaxEnt principle to the second normalized step of DEMATEL. Thirdly, based on DEMATEL, the cause-effect classification of factors can be obtained. Finally, the cause factor is identified as the critical success factors (CSFs) in emergency management.

The proposed method has the following two advantages:

From the perspective of information theory, the MaxEnt principle is used to determine the normalized direct influence matrix (DIM), which allows to obtain the normalized matrix with minimal information loss, and thus ensures the reasonableness and accuracy of the DEMATEL results.

From the perspective of information theory, this normalization method has a clear physical meaning and is interpretable.

The rest of paper is organized as follows: In the next section, the authors introduce the preliminaries of this work; subsequently, they present the proposed method; then, they illustrate an application in emergence management; after this, they discuss the rationality and superiority of the proposed method; finally, they end the paper with the conclusion.

PRELIMINARIES

Decision-Making Trial and Evaluation Laboratory Method

Gabus and Fontela (1972) proposed DEMATEL as a methodology for solving complex problems in the world. Si et al. (2018) detailed the algorithm of DEMATEL. As a structural modelling approach, it is particularly useful when analyzing the causal relationships between the components of a system. DEMATEL can identify the interdependencies between the factors and assist in the development of maps reflecting the relative relationships between the factors. Due to its superiority and capabilities, the approach of DEMATEL has had a great deal of attention in the last decade, with many researchers using it to solve problems in complex systems in various fields.

The direct impact matrix is usually built by the Delphi method. The DEMATEL algorithm initially uses the 0,1, 2, and 3 scales (i.e., 0 for no influence, while 1, 2, and 3 indicate small, medium, and large influences, respectively).

In addition, Wu et al. (2007) and Lin et al. (2018) extended this approach by proposing the use of 0, 1, 2, 3, and 4 evaluation scales to analyze complex problems, which experts have widely adopted, to date. The current construction of the direct impact matrix is based on the complexity of the analytical problem for the selection of the scale. However, the choice of the right scale is still open to discussion.

One of the important steps in DEMATEL is normalization. By means of normalization, it can eliminate the magnitude and accelerate the optimization process. Current normalization methods include the row-sum normalized method, the column-sum normalized method, the row-sum and column-sum normalized method, and the maximum value sine method. Table 1 shows the specific formulas (Abdullah et al., 2019; Yang et al., 2008).

Table 1. Some typical normalization methods

Normalization methods	The row-sum normalized method	The column-sum normalized method	The row-sum and column-sum normalized method	Maximum Value Sine Method
The mathematical expression	$Max(a)$	$Max(b)$	$Max[Max(a), Max(b)]$	$\sqrt{(Max(a))^2 + (Max(b))^2}$
Note	Where *a* is the set of sums of each row	Where *b* is the set of sums of each column	Where *a* is the set of sums of each row; where *b* is the set of sums of each column	Where *a* is the set of sums of each row; where *b* is the set of sums of each column

Conventional DEMATEL essentially defaults the normalized DIM to a zero matrix, otherwise the total influence matrix (TIM) is unsolvable. However, this assumption often does not correspond to the actual decision situation. For example, when all row sums of the DIM and column sums are equal, the TIM is unsolvable. For this problem, Lee et al. (2013) verified the reasoning by stating that a TIM is unsolvable and only when all the row sums of the DIM are normalized. Michnik (2020) also proposed a new DIM normalization method by calculating the sum of all the elements of the DIM, but without providing any mathematical derivation, so the scientific validity of this method needs to be further verified. Scholars have not agreed upon the core DEMATEL problem yet, namely how to normalize the mathematical treatment of DIMs.

MAXIMUM ENTROPY

Uncertainty plays an important role in real life (Deng, 2022). There are many math models, such as fuzzy sets (Baskaran & Eswari, 2021; Klir & Yuan, 1995; Pelusi et al., 2018b; Xiao, 2021a), evidence theory (Cheng & Xiao, 2021; Deng, 2020b; Song et al., 2022; Xiong et al.,2021), neural network (Pelusi et al., 2018a), complex evidence theory (Xiao, 2020, 2021b), information volume (Deng, 2020a; Gao et al., 2021), intuitionistic fuzzy sets (Xiao, 2021c; Xie et al., 2022), complex system modeling (Balakrishnan et al., 2021; Gao et al., 2021; Wang et al., 2022), decision-making models (Tang et al., 2021), and entropy (Cui et al., 2022; Song & Deng,2021; Song & Xiao, 2022). Among the tools, entropy is used to measure the amount of information and is a measure of discrete uncertainty. The more uncertain the system is, the greater its entropy.

The MaxEnt principle (Phillips et al., 2006) has its origins in thermodynamics. It has also been widely used in many optimization problems, including queuing systems, transportation, and portfolio optimization. In recent years, the MaxEnt has become the most successful machine learning method in the field of natural language processing (Li & Deng, 2021). The formula for MaxEnt is as follows:

$$\max S = -\sum_{i=1}^{n} p_i \ln p_i \tag{1}$$

To solve the optimization problem in Equation (1), the Lagrangian function is applied as shown below:

$$L \equiv -\sum_{i=1}^{n} p_i \ln p_i - \left(\beta_0 - 1\right)\left(\sum_{i=1}^{n} p_i - 1\right) - \sum_{r=1}^{m} \beta_r \left(\sum_{i=1}^{n} p_i g_{ri} - a_r\right) \tag{2}$$

where β_1, β_2, ..., β_m are Lagrange parameters. The Lagrange multipliers β_1, β_2,..., β_m are the partial derivatives of S_{max} with respect to a_1, a_2, a_m, respectively.

The probability distribution of a random quantity is difficult to determine, and generally only the mean (e.g., mathematical expectation or variance) or the value under certain conditions (e.g., peak value or number of values) can be measured. Selecting the distribution with the MaxEnt as the distribution of this random variable is an effective processing method. Although this method is subjective to some extent, it can be considered as the most suitable choice for the objective situation.

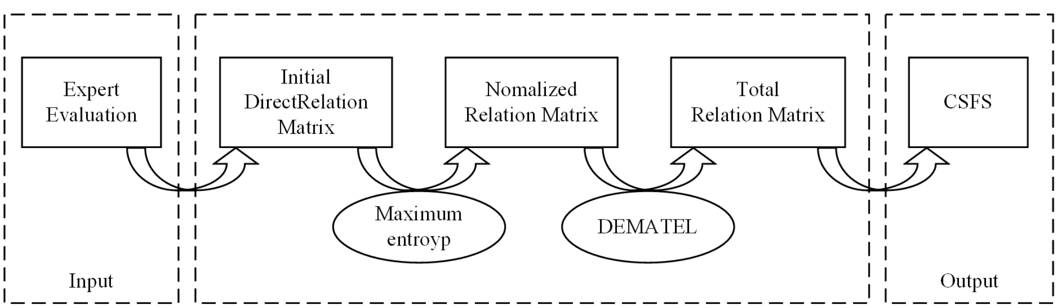
THE PROPOSED METHOD

Gabus and Fontela (1972) proposed DEMATEL as a methodology for solving complex problems in the world. It is also adopted to analyze the total relationship of the factors and divide the factors into cause categories and effect categories. As a result of its advantages and capabilities, the DEMATEL approach received much attention during the past few years. Reviewing the previous studies, DEMATEL was successfully used in various fields, such as construction projects (Hatefi & Tamosaitiene, 2019) and risk assessment (Deng & Jiang, 2020).

One of the important steps in DEMATEL is to normalize the DIM. The purpose of normalization is to make the preprocessed data be limited to a certain range ([0,1] or [-1,1]), thus eliminating the negative effects caused by abnormal sample data.The proposed method applies the MaxEnt principle to the second normalized step of DEMATEL. From the perspective of information theory, the MaxEnt principle is used to determine the normalized DIM, which allows to obtain the normalized matrix with minimal information loss, and thus ensures the reasonableness and accuracy of the DEMATEL results.

In this section, the authors propose a new method, called MaxEnt-based DEMATEL. The procedure is divided into the following four steps (Figure 1):

Figure 1. The flowchart of identifying CSFs in emergency management based onMaxEnt-DEMATEL



Step 1: Construct a direct relationship matrix.

To evaluate the relationship between n factors $F = \{ F_1, F_2, F_3, ..., F_n \}$ina system, assume that experts in a decision making group $E = \{ E_1, E_2, E_3, ..., E_n \}$ are requested to identify the direct impact that factor F_i has on factor F_j. Experts can firstly use natural language phrases, that is, five linguistic terms including "very low" (VL), "low" (L), "moderate" (M), "high" (H), and "very high" (VH) to determine the relative relationship.

Step 2: Normalization of the direct relationship matrix by using the MaxEnt principle.

After deriving the direct influence matrices from expert evaluations, the MaxEnt principle is used in the second normalized step of DEMATEL. The specific processes are as follows.

Firstly, assume that the direct relationship matrix is $P = \left[p_{ij}\right]_{n \times n}$ $(i, j = 1,2,3,4,...,n)$, where p_{ij} is the direct relation of F_i over F_j based on the measurement scale, and satisfies $p_{ij} = 0$ if $i = j$.

Secondly, sum all elements in the DIM via Equation (3):

$$S = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{ij} \tag{3}$$

Thirdly, the MaxEnt principle is introduced. Assume that the MaxEnt is x, and calculate the value of x through Equation (4). The purpose of this step is to minimize the information loss in the normalization process, and thus ensure the accuracy of the DEMATEL results:

$$X = -\sum p_i \ln p_i \tag{4}$$

Finally, the direct relationship matrix P is normalized by Equation (5) to obtain the normalization matrix $N = \left[n_{ij}\right]_{n \times n}$. All the elements in the matrix N are complying with $0 \leq n_{ij} \leq 1$:

$$N = \left(\frac{P}{S}\right)^{X} \tag{5}$$

Step 3: Construct the TIM.

In Equation (6), TIMs can be derived from the normalization matrix N, which are denoted as $T = \left[t_{ij}\right]_{n \times n}$,where t_{ij} indicates the total relation of F_i to F_j. The matrix N reflects the direct effect among factors. The TIM contains the direct and indirect relationships between the factors:

$$T = \left(N + N^2 + N^3 + \cdots + N^k\right) = \sum_{k=1}^{\infty} N^k \to T = N(I - N)^{-1} \tag{6}$$

where I is denoted as an identity matrix.

Step 4: Produce the influential relation map.

In this step, the vectors R and C represent the sum of rows and the sum of columns of the TIM, where R_i is the sum of the i_{th} row in matrix T, showing the sum of direct and indirect influences from factor F_i to other factors. Similarly, C_i is the sum of the i_{th} column in the matrix T, describing the sum of the direct and indirect influences that the factor F_i receives from the other factors.

Let $i = j$ and $i, j \in \{1,2,3,...,n\}$. The horizontal axis vector (R+C) named "Prominence" illustrates the strength of influences that are given and received from the factor. Alike, the vertical axis vector (R-C) called "Relation" shows the net effect that the factor contributes to the system. If (R_i - C_i) >0, then the factor F_i has a net influence on other factors and can be divided into cause groups. Conversely, if (R_i - C_i) <0, then the factor F_i is being influenced by the other factors and can be divided into effect groups. The factors in the cause category are finally identified as CSFs in emergency management.

In order to demonstrate the validity of the results, the authors have done experiments and compared the data between the current normalization method and the proposed new method. Assume that the DIM is Table 2. Then, the DIM can be normarlized by using different methods and the value of $R+C$ can be calculate. Table 3 shows the calculation results. Their analysis evidences that the new proposed method and method 2 obtained the same results: F4> F2> F3>F5> F1. However, the new proposed method comes to a different conclusion from the calculations of methods 1, 3, and 4, which give the result of F4>F2>F3 > F1>F5. This shows that the new proposed method reduces the amount of information lost with the introduction of MaxEnt. It also indicates that there is still room for improvement in the past normalization methods. Besides, the proposed method is applicable in the case of using the value of $R+C$ to determine the factor weights.

Table 2. The hypothetical direct influence matrix

	F1	F2	F3	F4	F5
F1	0	0	0	0	0
F2	4	0	2	4	0
F3	0	0	0	3	0
F4	0	0	2	0	2
F5	1	0	0	0	0

Table 3. Comparison of the ranking of R + C values under different normalization methods

R+C	Method1	Method 2	Method 3	Method 4	Method 5
	Max(a)	*Max(b)*	$Max[Max(a), Max(b)]$	$\sqrt{(Max(a))^2 + (Max(b))^2}$	*MaxEnt-DEMETEL*
F1	0.1139	0.1042	0.1139	0.1182	0.1038
F2	0.2745	0.2734	0.2745	0.2750	0.2470
F3	0.2178	0.2262	0.2178	0.2141	0.2354
F4	0.2932	0.2893	0.2932	0.2950	0.2861
F5	0.1006	0.1069	0.1006	0.0977	0.1232

An application in emergency management

In recent years, emergency management (Drabek & Hoetmer, 1991) has attracted a great deal of attention due to the frequency of disasters, such as the nuclear leak in Japan in 2017and the flash floods in Indonesia in 2018. In 2019, with the global outbreak of COVID-19, emergency management once again became a hot topic (Inwald et al., 2009).

Researchers have conducted many studies to improve emergency management. For example, Kim and Hastak (2018) analyzed the characteristics of online social networks after a disaster. Chen (2020) proposed a research of individuals' conformity behavior in emergency situations .The above methods are effective for optimizing emergency management. However, they also raise the following problems: They did not consider the issue from the perspective of information quantity, thus resulting in a loss of information. Indeed, in this situation, information is always insufficient because of the inherent complexity of emergency management.

As a result, researchers continue to investigate and design better methods to improve the success of the discovery process. Since the MaxEnt approach is designed to solve problems for the cases that have insufficient information, the authors believe that MaxEnt may be a good solution. In addition, it is difficult to optimize all aspects of emergency management. A more effective approach is to focus on the most urgent and important factors, that is on CSFs.

In this paper, the new method MaxEnt-based DEMATEL the authors propose combines the MaxEnt model with DEMATEL to identify CSF in emergency management. Based on the proposed method, the optimization of emergency management can be efficiently simplified into optimizing the identified CSFs. In this section, the authors present an example of using MaxEnt-based DEMATEL to identify CSFs in emergency management.

This example is based on the following hypotheses:

Hypothesis One: There are only 10 influential factors in emergency management.
Hypothesis Two: The expert's assessment is authoritative and persuasive.

Based on the last section, the CSF in emergency management is identified by the following steps:

Step 1: Expert evaluation on the direct relations of influential factors in emergency management.

Firstly, the authors summarize the factors influencing emergency management through an extensive literature review. Then, they identify 10 influential factors in emergency management and present them in Table 4.

Table 4. The influential factors in emergency management

Factor	Description	Literature sources
F1	Well-planned emergency relief supply system	Zhou et al., 2017
F2	Reasonable organizational structure and dear awareness	Han et al.,2018
F3	Applicable emergency response plan and regulations	Han et al.,2018
F4	Education campaign on disaster prevention and response	Kapucu et al.,2010
F5	Regular organization of simulated disaster exercise	Kapucu et al.,2010
F6	Government unity of leadership to plan and coordinate as a whole	Oh, N., & Lee, J. 2020
F7	Timely and accurate relief needs assessment	Oh, N., & Lee, J. 2020
F8	The security of relief aids during distribution and transportation	Oh, N., & Lee, J. 2020
F9	Gear procedure of reporting and submitting information	Tao et al.,2020
F10	Application of modern logistics technology	Tao et al.,2020

Next, the authors build the initial impact matrix by the Delphi method. Three experts from the Emergency Management Agency are requested to identify the direct impact that factor F_i has on factor F_j. Experts can firstly use natural language phrases, that is, five linguistic terms including "very low" (VL), "low" (L), "moderate" (M), "high" (H), and "very high" (VH) to determine the relative relationship. Then, according to the mapping rule from linguistic terms to IFN in Table 5, the authors can obtain the corresponding IFN decision matrix. The matrix is then fused (Zhou et al., 2017) (Table 6).

Table 5. Transform rules of linguistic variables of decision-maker for criteria performance of alternative.

Linguistic terms	IFNs
Very low(VL)	(0.10,0.85)
Low(L)	(0.30,0.65)
Moderate(M)	(0.50,0.50)
High(H)	(0.75,0.20)
Very high(VH)	(0.90,0.05)

Table 6. The Initial Influence Matrix

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.5	0.9275	0.915	0.8675	0.6788	0.7025	0.4338	0.1139	0.75	0.6413
F2	0.3138	0.5	0.5375	0.5513	0.3988	0.335	0.3975	0.5388	0.3675	0.6813
F3	0.585	0.725	0.5	0.81	0.605	0.7238	0.77	0.4588	0.5688	0.7125
F4	0.7188	0.7175	0.8938	0.5	0.71	0.8738	0.7938	0.6713	0.7875	0.78
F5	0.605	0.5625	0.3075	0.6425	0.5	0.785	0.7275	0.605	0.4825	0.625
F6	0.4425	0.4375	0.6625	0.6463	0.5	0.5	0.55	0.5375	0.5638	0.5313
F7	0.4513	0.8225	0.5863	0.9388	0.8313	0.7725	0.5	0.22	0.85	0.7838
F8	0.3688	0.6375	0.6938	0.895	1.1	0.575	0.3625	0.5	0.7625	0.475
F9	0.6375	0.3375	0.55	0.8475	0.7375	0.525	0.2125	0.34	0.5	0.4375
F10	0.4075	0.6125	0.6	0.8538	0.61	0.55	0.56	0.1975	0.47	0.5

Step 2: Normalization of the direct relationship matrix by using the MaxEnt.

After deriving the direct influence matrices from expert evaluations, the MaxEnt principle is used in the second normalized step of DEMATEL. The specific processes are as follows.

Firstly, construct the direct relationship matrix. Table 2 shows the direct relationship matrix evaluated by experts.

Secondly, sum all elements in the direct relation matrix via Equation (3).

Thirdly, the authors introduce the MaxEnt principle, and calculate the maximum value. Via Equation (4), the value is obtained at $x = 0.2$. The purpose of this step is to minimize the information loss in the normalization process, and thus ensure the accuracy of the DEMATEL results.

Finally, the direct relationship matrix is normalized by Equation (5) to obtain the normalized influence matrix (Table 7).

Table 7. The Normalized InfluenceMatrix

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	0.3840	0.4345	0.4333	0.4287	0.4082	0.4110	0.3732	0.2857	0.4164	0.4036
F2	0.3498	0.3840	0.3896	0.3916	0.3670	0.3544	0.3668	0.3898	0.3611	0.4085
F3	0.3962	0.4136	0.3840	0.4229	0.3989	0.4135	0.4186	0.3775	0.3940	0.4122
F4	0.4129	0.4128	0.4313	0.3840	0.4119	0.4294	0.4212	0.4073	0.4205	0.4197
F5	0.3989	0.3932	0.3484	0.4037	0.3840	0.4203	0.4139	0.3989	0.3813	0.4015
F6	0.3747	0.3739	0.4062	0.4042	0.3840	0.3840	0.3914	0.3896	0.3933	0.3887
F7	0.3762	0.4242	0.3964	0.4356	0.4251	0.4189	0.3840	0.3259	0.4270	0.4201
F8	0.3613	0.4031	0.4100	0.4314	0.4496	0.3949	0.3601	0.3840	0.4178	0.3801
F9	0.4031	0.3550	0.3914	0.4267	0.4150	0.3878	0.3236	0.3555	0.3840	0.3739
F10	0.3686	0.3999	0.3983	0.4274	0.3996	0.3914	0.3928	0.3189	0.3793	0.3840

Step 3: Use DEMATEL to identify the CSFs

In this step, the DEMATEL method is used to calculate the total relationship matrix of the influencing factors based on the normalized influence matrix. By using Equation (6), the total relationship matrix can be obtained (Table 8).

Table 8. The Total InfluenceMatrix

	F1	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*
F1	-0.1305	-0.1048	-0.1053	-0.1330	-0.1411	-0.1298	-0.1437	-0.2044	-0.1221	-0.1330
F2	-0.1413	-0.1250	-0.1197	-0.1379	-0.1469	-0.1580	-0.1254	-0.0752	-0.1461	-0.1024
F3	-0.1291	-0.1319	-0.1606	-0.1449	-0.1531	-0.1351	-0.1090	-0.1222	-0.1486	-0.1340
F4	-0.1277	-0.1488	-0.1303	-0.1975	-0.1550	-0.1354	-0.1230	-0.1077	-0.1381	-0.1434
F5	-0.1161	-0.1405	-0.1831	-0.1509	-0.1543	-0.1168	-0.1040	-0.0908	-0.1483	-0.1340
F6	-0.1318	-0.1533	-0.1207	-0.1434	-0.1475	-0.1451	-0.1187	-0.0921	-0.1303	-0.1400
F7	-0.1459	-0.1234	-0.1495	-0.1333	-0.1295	-0.1293	-0.1417	-0.1701	-0.1180	-0.1254
F8	-0.1562	-0.1400	-0.1330	-0.1327	-0.0977	-0.1476	-0.1616	-0.1031	-0.1215	-0.1621
F9	-0.0914	-0.1626	-0.1252	-0.1132	-0.1092	-0.1302	-0.1746	-0.1159	-0.1309	-0.1451
F10	-0.1327	-0.1230	-0.1250	-0.1186	-0.1318	-0.1332	-0.1099	-0.1577	-0.1418	-0.1379

Then, calculate the sum of rows R_i (i=1,2,3, …, m) and the sum of columns C_i (i=1,2,3, …, m) of the total relationship matrix. In terms of the value of $(R_i - C_i)$, factors are classified into causal and effect classes. Table 9 shows the final classification of the influencing factors. On the base of Table 6, the average importance of the factors is calculated and revealed in Table 10. Finally, five factors are identified as CSFs for emergency management. They are ranked as follows: F2>F9>F10>F6>F5.

Table 9. The classification and importance ranking of influential factors

	R	C	R - C
F1	-1.3477	-1.3028	-0.0449
F2	-1.2780	-1.3533	0.0753
F3	-1.3685	-1.3523	-0.0162
F4	-1.4069	-1.4056	-0.0014
F5	-1.3387	-1.3661	0.0274
F6	-1.3228	-1.3607	0.0379
F7	-1.3661	-1.3115	-0.0545
F8	-1.3556	-1.2391	-0.1165
F9	-1.2985	-1.3457	0.0472
F10	-1.3117	-1.3574	0.0456

Table 10. The classification and importance ranking of influential factors in emergencymanagement.

Factors	Ranking
F2	0.0753
F9	0.0472
F10	0.0456
F6	0.0379
F5	0.0274
F4	-0.0014
F3	-0.0162
F1	-0.0449
F7	-0.0545
F8	-0.1165

Discussion

The results in the previous section show that F2 (reasonable organizational structure and clear awareness of responsibilities) >F9 (clear procedure of reporting and submitting information) >F10 (application of modern logistics technology) >F6 (government unity of leadership to plan and coordinate as a whole) >F5 (regular organization of simulated disaster exercise) are identified as CSFs in emergency management.

In this section, the authors further explore the rationality and superiority of the proposed new method.

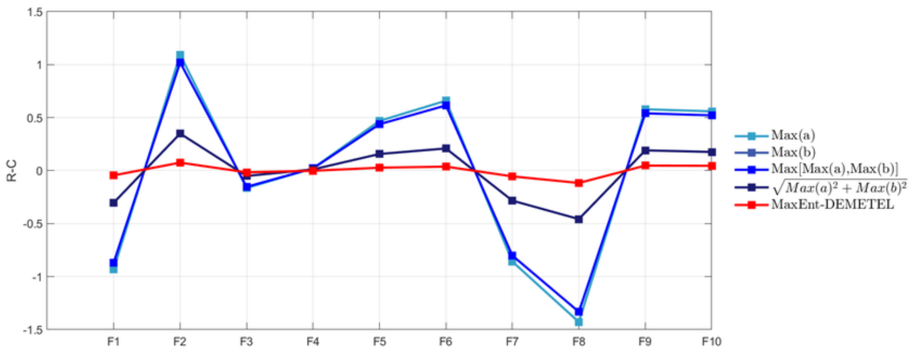
The authors compare the four typical normalization methods with the proposed new method,and the cause-effect classification and importance ranking of factors are shown in Table 11. Table 11 allows to observe that the CSFs the authors identified respectively by the four typical normalization methods and MaxEnt-DEMETEL are almost the same and contain F2, F5, F6, F9, and F10. This demonstrates that the results of the new method are reasonable. However, the ranking calculated by MaxEnt-DEMETEL is slightly different, compared to the typical four normalization methods. It ranked F9 in second place and F6 in fourth place. This suggests that, with the introduction of MaxEnt, making decisions from the perspective of the amount of information, F9 (i.e., the process of reporting and submitting information) is more important than F6 (i.e., unified government leadership, overall planning and coordination). The process of reporting and submitting information is important in times of emergency. This shows that the new proposed approach is more comprehensive in terms of the issues considered when making decisions.

Table 11. The cause-effect classification and importance ranking of factors.

	Max(a)	*Max(b)*	$Max[Max(a), Max(b)]$	$\sqrt{(Max(a))^2 + (Max(b))^2}$	*MaxEnt-DEMETEL*
Cause	F2	F2	F2	F2	F2
	F6	F6	F6	F6	F9
	F9	F9	F9	F9	F10
	F10	F10	F10	F10	F6
	F5	F5	F5	F5	F5
	F4	F4	F3	F4	-
Effect	F3	F3	F3	F3	F4
	F7	F7	F7	F7	F3
	F1	F1	F1	F1	F1
	F8	F8	F8	F8	F7
	-	-	-	-	F8

In addition, Figure 2 shows the importance of influential factors based on the same expert evaluation results and respectively calculated by the four typical normalization methods and MaxEnt-DEMETEL. Figure 2 suggests that the results obtained by the typical methods and MaxEnt-DEMETEL are partly similar, but differ in individual factors. From Table 11, the results obtained by MaxEnt-DEMETEL differ from those obtained by typical normalization methods, indicating that the introduction of MaxEnt does change the results of the calculation.

Figure 2. The importance of factors calculated by the four typical normalization methods and MaxEnt-DEMETEL



In previous research, scholars proposed many approaches to normalize the DIM. However, to the best of the authors' knowledge, there is no normalized method from the perspective of information theory. The current normalization method is usually applied by the geometrically relevant linear law, simply by taking the maximum value of the row sum. Thus, these methods result in a loss of information.

Therefore, MaxEnt is introduced, which is an effective tool for determining the amount of information present in the evidence. In the evaluation process, experts make judgments based on their experience and knowledge, and then the amount of information can be measured through MaxEnt. The more uncertain something is, the greater its entropy. When the entropy value is maximum, it means that the most information can be obtained from it. Emergency management involves many fields, as it is important to promote the overall welfare of an emergency management process from a higher perspective.

Compared with existing methods, MaxEnt-based DEMATEL can identify CSFs in emergency management from the perspective of the amount of information, which fully exploits the information and therefore can better simplify the optimization of emergency management.

Conclusion

With the recent occurrence of natural disasters, researchers pay more and more attention to emergency management. Although a large number of studies have been published, there is still room for improvement. In this paper, on the basis of MaxEnt and DEMATEL, the authors proposed the new method called MaxEnt-based DEMATEL to identify CSFs in emergency management. After expert assessment on the direct relations of influential factors in emergency management, MaxEnt is used to fully exploit the information. Then, by using DEMATEL, the total relationship of the factors can be derived and the factors are classified into cause or effect categories. The causal factors are determined as CSFs in emergency management. According to the proposed approach, the optimization of emergency management can be effectively simplified to the optimization of five CSFs.

In this paper, the authors demonstrated the efficiency and practicality of their proposed method by means of a numerical example and a real experiment. In summary, this paper provides a useful decision framework for emergency management evaluation, which, in addition, has good generality due to the following two points:

From the perspective of information theory, the MaxEnt principle is used to determine the normalized DIM, which allows to obtain the normalized matrix with minimal information loss, and thus ensures the reasonableness and accuracy of the DEMATEL results.

From the perspective of information theory, this normalization method has a clear physical meaning and is interpretable.

Although the proposed model is designed to deal with the selection problem of emergency events, it is also applicable to other multicriteria decision problems, such as CSF identification and supplier selection. In the future, the suggested approach can be extended to other areas to verify its usefulness.

Conflict of Interest

All the authors certify that there is no conflict of interest with any individual or organization for this work.

Funding Agency

The work is partially supported by National Natural Science Foundation of China [Grant No. 61973332], JSPS Invitational Fellowships for Research in Japan (Short-term).

ACKNOWLEDGMENT

The work is partially supported by National Natural Science Foundation of China [Grant No. 61973332], JSPS Invitational Fellowships for Research in Japan (short-term).

REFERENCES

Abdullah, L., Zulkifli, N., Liao, H., Herrera-Viedma, E., & Al-Barakati, A. (2019). An interval-valued intuitionistic fuzzy DEMATEL method combinedwith choquet integral for sustainable solid waste management. *Engineering Applications of Artificial Intelligence*, *82*, 207–215. doi:10.1016/j.engappai.2019.04.005

Altuntas, F., & Gok, M. S. (2021). The effect of covid-19 pandemic on domestictourism: A DEMATEL method analysis on quarantine decisions. *International Journal of Hospitality Management*, *92*, 102719. doi:10.1016/j.ijhm.2020.102719 PMID:33519015

Bai, C., & Sarkis, J. (2013). A grey-based DEMATEL model for evaluating business process management critical success factors. *International Journal of Production Economics*, *146*(1), 281292. doi:10.1016/j.ijpe.2013.07.011

Baskaran, N., & Eswari, R. (2021). Efficient VM selection strategies in cloud datacenter using fuzzy soft set. *Journal of Organizational and End User Computing*, *33*(5), 153–179. doi:10.4018/JOEUC.20210901.oa8

Büyüközkan, G., Güleryüz, S.,(2016). An integrated DEMATEL-ANP approachfor renewable energy resources selection in turkey. *International Journal of Production Economics, 182*, 435–448.

Chen, M. (2020). The research of human individual's conformity behaviorin emergency situations. *Library Hi Tech*, *38*(3), 593–609. doi:10.1108/LHT-08-2018-0113

Cheng, C., & Xiao, F. (2021). A distance for belief functions of orderable set. *Pattern Recognition Letters*, *145*, 165–170. doi:10.1016/j.patrec.2021.02.010

Cui, H., Zhou, L., Li, Y., & Kang, B. (2022). Belief entropy-of-entropy and itsapplication in the cardiac interbeat interval time series analysis. *Chaos, Solitons, and Fractals*, *155*, 111736. doi:10.1016/j.chaos.2021.111736

Deng, X., & Jiang, W. (2020). On the negation of a Dempster–Shafer belief structure based on maximum uncertainty allocation. *Information Sciences*, *516*, 346–352. doi:10.1016/j.ins.2019.12.080

Deng, Y. (2020a). Information volume of mass function. *International Journal of Computers, Communications & Control*, *15*(6), 3983. doi:10.15837/ijccc.2020.6.3983

Deng, Y. (2020b). Uncertainty measure in evidence theory. *Science China. Information Sciences*, *63*(11), 210201. doi:10.1007/s11432-020-3006-9

Deng, Y., (2022). Random permutation set. *International Journal of Computers Communications & Control, 17*, 4542. .10.15837/ijccc.2022.1.4542

Drabek, T. E., & Hoetmer, G. J. (1991). *Emergency management: Principlesand practice for local government*. International CityManagement Association.

Gabus, A., & Fontela, E., (1972). *World problems, an invitation to furtherthought within the framework of DEMATEL.* Academic Press.

Gao, Q., Wen, T., & Deng, Y. (2021). Information volume fractal dimension. *Fractals*, *29*(8), 2150263. doi:10.1142/S0218348X21502637

Han, Y., & Deng, Y. (2018). An enhanced fuzzy evidential DEMATEL method with its application to identify critical success factors. *Soft Computing*, *22*(15), 5073–5090. doi:10.1007/s00500-018-3311-x

Hatefi, S. M., & Tamošaitienė, J. (2019). An integrated fuzzy DEMATEL-fuzzyANP model for evaluating construction projects by considering interrelationships among risk factors. *Journal of Civil Engineering and Management*, *25*(2), 114–131. doi:10.3846/jcem.2019.8280

Inwald, D.P., Tasker, R.C., Peters, M.J., & Nadel, S. (2009). Emergency management of children with severe sepsis in the United Kingdom: the results of the paediatric intensive care society sepsis audit. *Archives of Disease in Childhood, 94*, 348–53.

Kapucu, N., Arslan, T., & Demiroz, F. (2010). Collaborative emergency management and national emergency management network. *Disaster Prevention and Management*. *International Journal*.

Karayalcin, I. I. (1982). *The analytic hierarchy process: planning, priority setting, resource allocation: Thomas L. Saaty.* McGraw-Hill.

Kim, J., & Hastak, M. (2018). Social network analysis: Characteristics of online social networks after a disaster. *International Journal of Information Management*, *38*(1), 86–96. doi:10.1016/j.ijinfomgt.2017.08.003

Klir, G., & Yuan, B. (1995). *Fuzzy set and fuzzy logic: Theory and applications*. Academic Press.

Lee, H. S., Tzeng, G. H., Yeih, W., Wang, Y. J., & Yang, S. C. (2013). Revised DEMATEL: Resolving the infeasibility of DEMATEL. *Applied Mathematical Modelling*, *37*(10-11), 6746–6757. doi:10.1016/j.apm.2013.01.016

Li, D., & Deng, Y. (2021). Measure information quality of basic probabilityassignment: An information volume method. *Applied Intelligence*. Advance online publication. doi:10.1007/s10489-021-03066-y

Liu, T., Deng, Y., & Chan, F. (2018). Evidential supplier selection based on DEMATEL and game theory. *International Journal of Fuzzy Systems*, *20*(4), 1321–1333. doi:10.1007/s40815-017-0400-4

Oh, N., & Lee, J. (2020). Changing landscape of emergency management research: A systematic review with bibliometric analysis. *International Journal of Disaster Risk Reduction*, *49*, 101658. doi:10.1016/j.ijdrr.2020.101658

Pelusi, D., Mascella, R., & Tallini, L. (2018a). A fuzzy gravitational search algorithm to design optimal IIR filters. *Energies*, *11*(4), 736. doi:10.3390/en11040736

Pelusi, D., Mascella, R., Tallini, L., Nayak, J., Naik, B., & Abraham, A. (2018b). Neural network and fuzzy system for the tuning of gravitational search algorithm parameters. *Expert Systems with Applications*, *102*(JUL), 234–244. doi:10.1016/j.eswa.2018.02.026

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, *190*(3-4), 231–259. doi:10.1016/j.ecolmodel.2005.03.026

Si, S.L., You, X.Y., Liu, H.C., & Ping, Z. (2018). Dematel technique: A systematic review of the state-of-the-art literature on methodologies and applications. *Mathematical Problems in Engineering*, 1–33.

Song, M., Sun, C., Cai, D., Hong, S., & Li, H. (2022). Classifying vaguely labeled data based on evidential fusion. *Information Sciences*, *583*, 159–173. doi:10.1016/j.ins.2021.11.005

Song, X., & Xiao, F. (2022). Combining time-series evidence: A complex network model based on a visibility graph and belief entropy. *Applied Intelligence*. Advance online publication. doi:10.1007/s10489-021-02956-5

Song, Y., & Deng, Y. (2021). Entropic explanation of power set. *International Journal of Computers, Communications & Control*, *16*(4), 4413. doi:10.15837/ijccc.2021.4.4413

Tang, G., & Zeng, H. (2021). Evaluation of tourism E-commerce user satisfaction. *Journal of Organizational and End User Computing*, *33*(5), 25–41. doi:10.4018/JOEUC.20210901.oa2

Tao, J., Song, Z., Yang, L., Huang, C., Feng, A., & Man, X. (2020). Emergency management for preventing and controlling nosocomial infection of the 2019 novel coronavirus: Implications for the dermatology department. *British Journal of Dermatology*, *182*(6), 1477–1478. doi:10.1111/bjd.19011 PMID:32141058

Wang, T., Liu, W., Cabrera, L. V., Wang, P., Wei, X., & Zang, T. (2022). A Novel Fault Diagnosis Method of Smart Grids based on Memory Spiking Neural P Systems Considering Measurement Tampering Attacks. *Information Sciences*, *596*, 520–536. doi:10.1016/j.ins.2022.03.013

Wu, W. W. (2008). Choosing knowledge management strategies by usinga combined ANP and DEMATEL approach. *Expert Systems with Applications*, *35*(3), 828–835. doi:10.1016/j.eswa.2007.07.025

Wu, W. W., & Lee, Y. T. (2007). Developing global managers' competenciesusing the fuzzy dematel method. *Expert Systems with Applications*, *32*(2), 499–507. doi:10.1016/j.eswa.2005.12.005

Xiao, F. (2020). Generalization of Dempster–Shafer theory: A complex mass function. *Applied Intelligence*, *50*(10), 3266–3275. doi:10.1007/s10489-019-01617-y

Xiao, F. (2021a). CaFtR: A fuzzy complex event processing method. *International Journal of Fuzzy Systems*. Advance online publication. doi:10.1007/s40815-021-01118-6

Xiao, F. (2021b). CEQD: A complex mass function to predict interference effects. *IEEE Transactions on Cybernetics*, 1–13. Advance online publication. doi:10.1109/TCYB.2020.3040770 PMID:33400662

Xiao, F. (2021c). A distance measure for intuitionistic fuzzy sets and its application to pattern classification problems. *IEEE Transactions on Systems, Man, and Cybernetics. Systems*, *51*(6), 3980–3992. doi:10.1109/TSMC.2019.2958635

Xie, D., Xiao, F., & Pedrycz, W. (2022). Information quality for intuitionistic fuzzy values with its application in decision making. *Engineering Applications of Artificial Intelligence*, *109*, 104568. doi:10.1016/j.engappai.2021.104568

Xiong, L., Su, X., & Qian, H. (2021). Conflicting evidence combination from the perspective of networks. *Information Sciences*, *580*, 408–418. doi:10.1016/j.ins.2021.08.088

Yang, Y.P.O., Shieh, H.M., Leu, J.D., Tzeng, G.H., (2008). A novel hybridmcdm modelcombined with DEMATEL and ANP with applications. *International Journal of Operations Research, 5*, 160–168.

Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A., & Nor, K. M. (2016). Development of TOPSIS method to solve complicated decision-makingproblems—An overview on developments from 2000 to 2015. *International Journal of Information Technology & Decision Making*, *15*(03), 645–682. doi:10.1142/S0219622016300019

Zhang, W., & Deng, Y. (2019). Combining conflicting evidence using the DEMATEL method. *Soft Computing*, *23*(17), 8207–8216. doi:10.1007/s00500-018-3455-8

Zhou, X., Shi, Y., Deng, X., & Deng, Y. (2017). D-DEMATEL: A new methodto identify critical success factors in emergency management. *Safety Science*, *91*, 93–104. doi:10.1016/j.ssci.2016.06.014

Yuelin Che received her Bachelor of Science in Management from Jin cheng College of Sichuan University, Chengdu, China in 2018. Currently, she is a postgraduate student in the School of Economics and Management, University of Electronic Science and Technology, Chengdu, China. Her research interests are mainly focused on decision making and emergency management.

Yong Deng received the Ph.D. degree in Precise Instrumentation from Shanghai Jiao Tong University, Shanghai, China, in 2003. Now he is the full professor of Institute of Fundamental and Frontier Science, University of Electronic Science and Technology of China, Chengdu, China. Professor Deng has published more than 100 papers in referred journals. His research interests include evidence theory, decision making, information fusion and complex system modelling. He severed as many editorial board members such as Editorial Board Member of Applied Intelligence, Academic Editor of the PLOS ONE and Reviewer Board Member of Journal of Organizational and End User Computing. He severed as many guest editor such as International Journal of Approximate Reasoning, Mathematical Problems in Engineering and Sustainability. He severed as the reviewer for more than 30 journals. Professor Deng has received numerous honors and awards, including the Elsevier Highly Cited Scientist in China from 2014 to present.

Yu-Hsi Yuan is the coauthor of this paper. Dr. Yuan received his PhD from the Department of Industrial Education, National Taiwan Normal University in 2012. Now he serves as an Associate Professor in the Department of Labor and Human Resources, Chinese Culture University, Taipei, Taiwan. His research interest in management, e-commerce study, marketing strategy, human resources, and data mining.