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Identification of a threshold value for the DEMATEL method using the maximum mean de-entropy algorithm to find critical services provided by a semiconductor intellectual property mall

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ABSTRACT

To deal with complex problems, structuring them through graphical representations and analyzing causal influences can aid in illuminating complex issues, systems, or concepts. The DEMATEL method is a methodology which can confirm interdependence among variables and aid in the development of a chart to reflect interrelationships between variables, and can be used for researching and solving complicated and intertwined problem groups. The end product of the DEMATEL process is a visual representation—the impact-relations map—by which respondents organize their own actions in the world. In order to obtain a suitable impact-relations map, an appropriate threshold value is needed to obtain adequate information for further analysis and decision-making. In the existing literature, the threshold value has been determined through interviews with respondents or judged by the researcher. In most cases, it is hard and time-consuming to aggregate the respondents and make a consistent decision. In addition, in order to avoid subjective judgments, a theoretical method to select the threshold value is necessary. In this paper, we propose a method based on the entropy approach, the maximum mean de-entropy algorithm, to achieve this purpose. Using a real case to find the interrelationships between the services of a Semiconductor Intellectual Property Mall as an example, we will compare the results obtained from the respondents and from our method, and show that the impact-relations maps from these two methods could be the same.

1. Introduction

The DEMATEL (Decision-Making Trial and Evaluation Laboratory) method, developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976, was used to research and solve complicated and intertwined problem groups (Fontela & Gabus, 1974, 1976). DEMATEL was developed in the hope that pioneering the appropriate use of scientific research methods could improve the understanding of a specific *problematique*, a cluster of intertwined problems, and contribute to the identification of workable solutions through a hierarchical structure. The DEMATEL method is based on graph theory, enabling us to plan and solve problems visually, so that we may divide the relevant factors into cause and effect groups in order to better understand causal relationships. The methodology can confirm interdependence among variables and aid in the development of a directed graph to reflect the interrelationships between variables.

The applicability of the DEMATEL method is widespread, ranging from analyzing world problematique decision-making to industrial planning (Chiu, Chen, Shyu, & Tzeng, 2006; Hori & Shimizu, 1999; Huang, Shyu, & Tzeng, 2007; Tzeng, Chiang, & Li, 2006). The most important property of the DEMATEL method used in the multi-criteria decision-making (MCDM) field is to construct interrelations between criteria. After the interrelations between criteria were determined, the results derived from the DEMATEL method could be used for fuzzy integrals to measure the super-additive effectiveness value or for the Analytic Network Process method (ANP) (Liou, Yen, & Tzeng, 2008; Saaty, 1996; Tsai & Chou, 2009) to measure dependence and feedback relationships between certain criteria. When the DEMATEL method is used as part of a hybrid MCDM model, the results of the DEMATEL will influence the final decision.

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There are four steps in the DEMATEL method: (1) calculate the average matrix, (2) calculate the *normalized initial direct-influence matrix*, (3) derive the*total relation matrix*, and (4) set a threshold value and obtain the *impact-relations map* (in Fig. 1, we divided Step 4 into two steps). In Step 4, an appropriate threshold value is necessary to obtain a suitable impact-relations map as well as adequate information for further analysis and decision-making. The traditional method followed to set a threshold value is conducting discussions with experts. The researcher sets an adequate threshold value and then outlines an impact-relations map to discuss whether the impact-relations map is suitable for the structure of the problematique. If not, the threshold value is replaced by another value, and another impact-relations map is obtained until there is a consistent opinion among the majority. Sometimes, after the researcher obtains the input data for Step 1 using questionnaires, it is difficult to choose a consistent threshold value, especially if there are too many experts to aggregate at the same time. When the factors of the problem are many, the work involved in obtaining a consistent threshold value becomes more complex. In order to obtain a reasonable threshold value with respect to difficulty in the discussions with experts, the researcher may choose the value subjectively. The results of the threshold values may differ among different researchers.

In contrast to the traditional method, which confronts the loop from a "set a threshold value" to obtain "the needed impact-relations map", as shown in Fig. 1, we propose the maximum mean de-entropy (MMDE) algorithm to obtain a threshold value for delineating the impact-relations map. This algorithm based on the entropy approach can be used to derive a set of *dispatch-nodes*, the factors which strongly dispatch influences to others, and a set of *receive-nodes*, which are easily influenced by another factor. According to these two sets, a unique threshold value can be obtained for the impact-relations map.

In the numerical example, a real case is used to discover and illustrate the key services needed to attract Semiconductor Intellectual Property Mall (SIP) users and SIP providers to an SIP Mall. Research in the current study enabled the derivation of the interrelated services and their structural interrelationships using the DEMATEL method, where the threshold value is selected through discussions with experts. By using the proposed MMDE algorithm to choose the threshold value, both impact-relations maps from the traditional method and the algorithm we propose are the same, although the procedures are different.

The rest of this paper is organized as follows: Section 2 briefly describes the DEMATEL method. The steps of the maximum mean de-entropy algorithm will be described, explained, and discussed in Section 3. In Section 4, a numerical example, a real case where the goal is to find out the interrelated services that should be provided by a semiconductor intellectual properties mall and the structural interrelationship between them, is shown in order to explain the proposed algorithm and discuss the results. Finally, in Section 5, we draw conclusions.

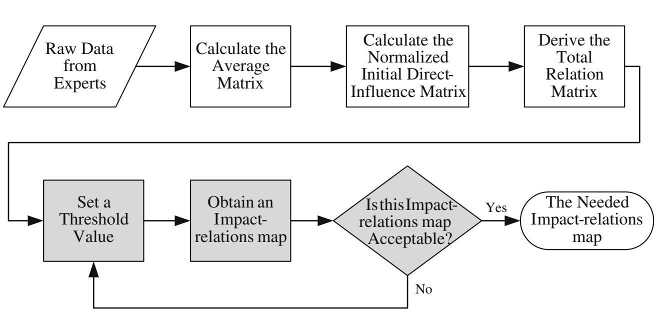

Fig. 1. The steps of the DEMATEL method.

2. DEMATEL method

The end product of the DEMATEL process—the impact-relations map—is a visual representation of the mind by which the respondent organizes his or her own action in the world. This organizational process must occur for the respondent to keep internally coherent and to reach his or her personal goals. The steps of the DEMATEL method (Tzeng et al., 2006) are described as follows:

Step 1: Find the average matrix.Suppose there are h experts available to solve a complex problem and there are $n$factors to be considered. The scores given by each expert give us a $n \times n$ non-negative answer matrix $\boldsymbol{X}^k$, with $1 \leqslant k \leqslant h$. Thus $\boldsymbol{X}^1, \boldsymbol{X}^2, \ldots, \boldsymbol{X}^h$ are the answer matrices for each of the h experts, and each element of $\boldsymbol{X}^k$ is an integer denoted by x_{ij}^k. The diagonal elements of each answer matrix $\boldsymbol{X}^k$ are all set to zero. We can then compute the $n \times n$ average matrix $\boldsymbol{A}$by averaging the h experts' score matrices. The (i,j) element of matrix $\boldsymbol{A}$ is denoted by a_{ij},

$$a_{ij} = \frac{1}{h} \sum_{k=1}^{h} x_{ij}^k. \tag{1}$$

In application, respondents were asked to indicate the direct-influence that they believe each factor exerts on each of the others according to an integer scale ranging from 0 to 4. A high score from a respondent indicates a belief that greater improvement in i is required to improve j. From any group of direct matrices of respondents, it is possible to derive an average matrix $\boldsymbol{A}$.

Step 2: Calculate the normalized initial direct-relation matrix.We then create a matrix $\boldsymbol{D}$ by using a simple matrix operation on $\boldsymbol{A}$. Suppose we create matrix $\boldsymbol{D}$ and $D = s \cdot A$ where

$$s = Min\left[\frac{1}{\max_{1 \leqslant i \leqslant n} \sum_{j=1}^{n} |a_{ij}|}, \frac{1}{\max_{1 \leqslant j \leqslant n} \sum_{i=1}^{n} |a_{ij}|}\right]. \tag{2}$$

Matrix $\boldsymbol{D}$ is called the *normalized initial direct-relation matrix*. The (i,j) element d_{ij} denotes the direct-influence from factor x_i to factor x_j. Suppose d_i denotes the row sum of the ith row of matrix $\boldsymbol{D}$.

$$d_{i\bullet} = \sum_{j=1}^{n} d_{ij}. \tag{3}$$

The d_i shows the sum of influence directly exerted from factor x_i to the other factors. Suppose d_j denotes the column sum of the jth column of matrix $\boldsymbol{D}$.

$$d_{\bullet j} = \sum_{i=1}^{n} d_{ij}. \tag{4}$$

Then d_j shows the sum of influence that factor x_j received from the other factors. We can normalize d_i and d_j as

$$w_i(d) = \frac{d_{i\bullet}}{\sum_{i=1}^{n} d_{i\bullet}}, \tag{5}$$

$$\upsilon_j(d) = \frac{d_{\bullet j}}{\sum_{j=1}^{n} d_{\bullet j}}. \tag{6}$$

Matrix $\boldsymbol{D}$ shows the initial influence which a factor exerts and receives from another. Each element of matrix $\boldsymbol{D}$ portrays a contextual relationship among the elements of the system and can be converted into a visible structural model—an *impact-relations map*—of the system with respect to that relationship. For example, as shown in Fig. 2, the respondents are requested to indicate only direct links. In the directed graph represented in Fig. 2, factor i directly affects only factors j and k; while indirectly, it also affects

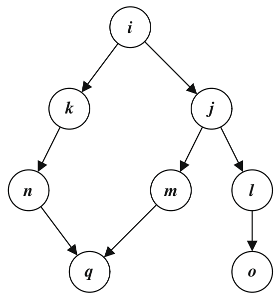

Fig. 2. Example of a direct graph.

first l, m, and n and, secondly, o and q. The digraph map helps to explain the structure of the factors.

Step 3: A continuous decrease of the indirect effects of problems along the powers of matrix $\boldsymbol{D}$, e.g. $\boldsymbol{D}^2, \boldsymbol{D}^3, \ldots, \boldsymbol{D}^{\infty}$, guarantees convergent solutions to the matrix inversion, similar to an absorbing Markov chain matrix. Note that $\lim_{m\to\infty} D^m = [0]_{n\times n}$, where $[0]_{n\times n}$ is the $n \times n$ null matrix. The total relation matrix $\boldsymbol{T}$ is an $n \times n$ matrix and is defined as follows:

$$\begin{aligned}\sum_{m=1}^{\infty} D^i &= D + D^2 + D^3 + \cdots + D^m \\ &= D\left(\mathbf{I} + D + D^2 + D^3 + \cdots + D^{m-1}\right) \\ &= D(\mathbf{I} - D)^{-1}(I - D)\left(\mathbf{I} + D + D^2 + D^3 + \cdots + D^{m-1}\right) \\ &= D(\mathbf{I} - D)^{-1}(\mathbf{I} - D^m) = D(\mathbf{I} - D)^{-1}, \end{aligned} \tag{7}$$

where $\boldsymbol{I}$ is the identity matrix and $\boldsymbol{T}$ is called the *total relation matrix*. The (i,j) element of the matrix $\boldsymbol{T}$, t_{ij}, denotes the full direct- and indirect-influence exerted from factor x_i to factor x_j. Like the formula (3)–(6), we can obtain t_i, t_j, $w_i(t)$, and $v_j(t)$.

Step 4: Set a threshold value and obtain the impact-relations map.

In order to explain the structural relationship among the factors while keeping the complexity of the system to a manageable level, it is necessary to set a threshold value p to filter out the negligible effects in matrix $\boldsymbol{T}$. Using the values of $w_i(t)$ and $v_i(t)$ from the matrix of full direct/indirect-influence relations, the level of dispatching and receiving of the influence of factor i can be defined. The interrelationship of each factor can be visualized as the oriented graphs on a two-dimensional plane after a certain threshold is set. Only those factors that have an effect in matrix $\boldsymbol{T}$ greater than the threshold value should be chosen and shown in an impact-relations map.

In Step 4, the threshold value can be chosen by the decision maker or through discussions with experts. If the threshold value is too low, the map will be too complex to show the necessary information for decision-making. If the threshold value is too high, many factors will be presented as independent factors, without showing the relationships with other factors. Each time the threshold value increases, some factors or relationships will be removed from the map (an example based on a total relation matrix $\boldsymbol{T}^{\text{example}}$ is shown as formula (8) and in Fig. 3). An appropriate threshold value is necessary to obtain a suitable impact-relations map as well as adequate information for further analysis and decision-making.

$$\boldsymbol{T}^{\text{example}} = \begin{bmatrix} 0.0093 & 0.0126 & 0.0538 & 0.0523 & 0.0759 \\ 0.0284 & 0.0077 & 0.0292 & 0.0284 & 0.0517 \\ 0.0509 & 0.0729 & 0.0087 & 0.0299 & 0.0341 \\ 0.0313 & 0.0340 & 0.0531 & 0.0086 & 0.0752 \\ 0.0532 & 0.0758 & 0.0547 & 0.0532 & 0.0150 \end{bmatrix}. \tag{8}$$

3. Maximum mean de-entropy algorithm (MMDE)

As we mentioned above, the threshold value is determined by asking experts or by the researcher (as a decision maker). Choosing a consistent threshold value is time-consuming if the impact-relations maps are similar when threshold values are changed slightly. If we consider the total relation matrix as a partially ordered set, the order relation is decided by the influence value. The question about deciding a threshold value is equal to a real point set divided into two subsets: one subset provides information on the obvious inter-dependent relationships of factors but the relationships are considered not so obvious in another subset. The proposed algorithm is a way to choose the "cut point".

We propose the maximum mean de-entropy (MMDE) algorithm to find a threshold value for delineating the impact-relations map. In this algorithm, we use the approach of entropy, which has been widely applied in information science, but define another two information measures: *de-entropy* and *mean de-entropy*. In addition, the proposed algorithm mainly serves to search for the threshold value by nodes (or vertices). This algorithm differs from the traditional methods through which the threshold value is decided by searching a suitable impact-relations map.

In this section, we use the symbol ■ as the end of a definition or a step in the proposed algorithm.

3.1. Information entropy

Entropy is a physical measurement of thermal-dynamics and has become an important concept in the social sciences (Kartam, Tzeng, & Tzeng, 1993; Zeleny, 1981). In information theory, entropy is used to measure the expected information content of certain messages, and is a criterion for the amount of "uncertainty" represented by a discrete probability distribution.

Definition 1. Let a random variable with n elements be denoted as $X = \{x_1, x_2, \ldots, x_n\}$, with a corresponding probability $P = \{p_1, p_2, \ldots, p_n\}$, then we define the entropy, H, of X as follows:

$$H(p_1, p_2, \ldots, p_n) = -\sum p_i \lg p_i$$

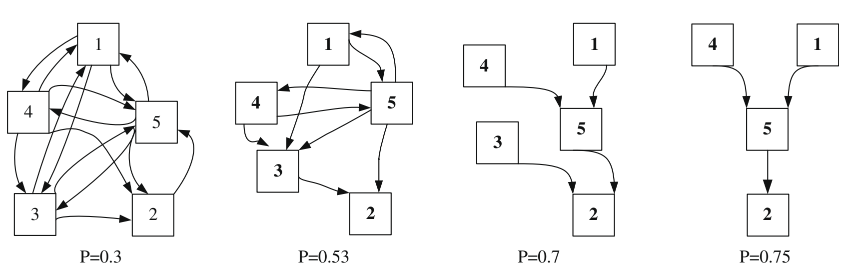

Fig. 3. Impact-relations maps based on the same total relation matrix but different threshold values.

subject to constraints (9) and (10):

$$\sum_{i=1}^{n} p_i = 1, \tag{9}$$

$$p_i \lg p_i = 0 \quad \text{if } p_i = 0. \quad \blacksquare \tag{10}$$

By Definition 1, the value of $H(p_1,p_2,\ldots,p_n)$ is the largest when $p_1 = p_2 = \cdots = p_n$ and we denote this largest entropy value as $H(\frac{1}{n},\frac{1}{n},\ldots,\frac{1}{n})$. Now we will define another measure for the decreased level of entropy: *de-entropy*.

Definition 2. For a given finite discrete scheme of X, the *de-entropy* of X is denoted as H^D and defined as:

$$H^D = H\left(\frac{1}{n},\frac{1}{n},\ldots,\frac{1}{n}\right) - H(p_1,p_2,\ldots,p_n) \quad \blacksquare$$

By Definition 2, the value of H^D is equal to or larger than 0. Unlike entropy, which is used for the measure of uncertainty, the H^D can explain the amount of useful information derived from a specific dataset, which reduces the "uncertainty" of information. We define the de-entropy for searching the threshold value in order to assess the effect of information content when adding a new node to an existing impact-relations map. By Definition 1, formula (11) can be proven (the proof can be found in (Khinchin, 1957)):

$$H_n = H\left(\frac{1}{n},\frac{1}{n},\ldots,\frac{1}{n}\right) \leqslant H\left(\frac{1}{n+1},\frac{1}{n+1},\ldots,\frac{1}{n+1}\right) = H_{n+1} \tag{11}$$

Formula (11) explains that when adding a new variable to a system where all variables in the system have the same probability, the entropy of the system will increase.

To delineate an impact-relations map, if adding a new factor to the impact-relations map can make the system less uncertain, or lead to more de-entropy, then the new factor provides worthwhile information for a decision maker. In other words, in an existing information system whose variables and corresponding probabilities have been fixed, adding a new variable to the system will change the probability distribution; if $H^D_{n+1} > H^D_n$ exists, then this new variable provides useful information to avoid uncertainty for the decision maker.

3.2. The dispatch- and receive-nodes

In the DEMATEL method, the total relation matrix is the matrix used to delineate the final output of the DEMATEL method, the impact-relations map, after the threshold value is determined. As in the notation in Section 2, an $n \times n$ total relation matrix is denoted as $\boldsymbol{T}$. The (i,j) element of the matrix $\boldsymbol{T}$, t_{ij}, refers to the full direct- and indirect-influence exerted from factor x_i to factor x_j. Like the "vertices" and "edges" in graph theory (Agnarsson & Greenlaw, 2007), x_i and x_j are vertices in the directed graph impact-relations map, and t_{ij} can be considered as a directed edge which connects factors x_i and x_j with an influence value. In an impact-relations map, every factor may influence, or be influenced by, another factor, or both.

Definition 3. The (i,j) element of the matrix T is denoted as t_{ij} and refers to a directed influence relations from factor x_i to factor x_j. For each t_{ij}, the factor x_i is defined as a *dispatch-node* and factor x_j is defined as a *receive-node* with respect to t_{ij}. ■

By Definition 2, an $n \times n$ total relation matrix $\boldsymbol{T}$ can be considered as a set (set T) with n^2 pair ordered elements. Every subset of set T can be divided into two sets: an ordered dispatch-node set and an ordered receive-node set. For an ordered dispatch-node set (or an ordered receive-node set), we can count the frequency of the different elements of the set. If the finite cardinality of an order dispatch-node set (or an ordered receive-node set) is m and the frequency of element x_i is k, we assign the corresponding probability of x_i as $p_i = \frac{k}{m}$. In this way, for an ordered set, we can assign each different element a probability and follow Definition 1 for $\sum_{i=1}^{n} p_i = 1$.

Notation. In this paper, $C(X)$ denotes the cardinal number of an ordered set X and $N(X)$ denotes the cardinal number of different elements in set X. For example, if $X = \{1,2,2,3,1\}, C(X) = 5$ and $N(X) = 3$.

3.3. Maximum mean de-entropy algorithm

Based on a calculated total relation matrix $\boldsymbol{T}$, the steps of the proposed maximum mean de-entropy algorithm for determining a threshold value are described as follows:

Step 1: Transforming the $n \times n$ total relation matrix $\boldsymbol{T}$ into an ordered set $T, \{t_{11}, t_{12}, \ldots, t_{21}, t_{22}, \ldots, t_{nn}\}$, rearranging the element order in set T from large to small, and transforming to a corresponding ordered triplets (t_{ij}, x_i, x_j) set denotes T^*. ■
Every element of set T, t_{ij}, can also be considered as an ordered triplet (t_{ij}, x_i, x_j) as (influence value, dispatch-node, receive-node). As the matrix $\boldsymbol{T}^{\text{example}}$ of the example mentioned above, the transformed and rearranged set, T^{example}, is $\{0.0759, 0.0758, 0.0752, \ldots, 0.0077\}$. The ordered triplets set is $\{(0.0759,1,5), (0.0758,5,2), (0.0752,4,5), \ldots, (0.0077,2,2)\}$ and the cardinal number of $T^{*\text{example}}$, $C(T^{*\text{example}})$, is 25.

Step 2: Taking the second element, the dispatch-node, from the ordered triplets of the set T^* and then obtaining a new ordered dispatch-node set, T^{Di}. ■
According to the set T^*, we can derive the corresponding ordered dispatch-node set. As the set $T^{*\text{example}}$ of the example in Step 1, the ordered dispatch-node set T^{Di} is $\{1,5,4,\ldots,2\}$ and $C(T^{Di})$ is also 25.

Step 3: Taking the first t elements of T^{Di} as a new set T^{Di}_t, assign the probability of different elements, and then calculate the H^D of the set T^{Di}_t, H^{Di}_t. We can calculate the *mean de-entropy* by $MDE^{Di}_t = \frac{H^{Di}_t}{N(T^{Di}_t)}$. At first, the t is set as 1, then of value of t is determined by raising the value from 1 to $C(T^{Di})$ in increments of 1. ■
Why we use $\frac{H^{Di}_t}{N(T^{Di}_t)}$ as "mean de-entropy" rather than $\frac{H^{Di}_t}{C(T^{Di}_t)}$ must be clarified. Regardless of how many times a dispatch-node repeats in a set T^{Di}_t, this dispatch-node will show in the impact-relations map only once if we use this T^{Di}_t to draw the impact-relations map. The H^{Di}_t is the de-entropy of $N(T^{Di}_t)$ dispatch-nodes in the impact-relations map, not $C(T^{Di}_t)$ dispatch-nodes. In this step, we can obtain $C(T^{Di})$ mean de-entropy values. As the set $T^{*\text{example}}$, we will obtain 25 mean de-entropy values.

Step 4: In $C(T^{Di})$ mean de-entropy values, select the *maximum mean de-entropy* and its corresponding T^{Di}_t. This dispatch-node set, with the maximum mean de-entropy, is denoted as $T^{Di}_{\max}$. ■

Step 5: Similar to Steps 2–4, an ordered receive-node set T^{Re} and a maximum mean de-entropy receive-node set $T^{Re}_{\max}$ can be derived. ■

Step 6: Taking the first u elements in T^* as the subset, T^{Th}, which includes all elements of $T^{Di}_{\max}$ in the dispatch-node and all elements of $T^{Re}_{\max}$ in the receive-node, the minimum influence value in T^{Th} is the threshold value, and formula (12) holds

$$1 < C(T^{Th}) < C(T^*) \quad \blacksquare \tag{12}$$

In Step 6, the elements of $T^{Di}_{\max}$ are the "more important" factors which provide more information about influence dispatching for a decision maker than other factors. The elements of $T^{Re}_{\max}$ provide information on which are easily influenced. If we use the ordered triplets $T^{Th}, T^{Di}_{\max}$, and $T^{Re}_{\max}$ in the structured directed graphs $G(T^{Th}), G(T^{Di}_{\max})$ and $G(T^{Re}_{\max})$, formula (13) holds.

$$G(T^{Th}) = G(T^{Di}_{\max}) \cup G(T^{Re}_{\max}) \tag{13}$$

with the property of

$$G\left(T^{Di}_{\max}\right) = G\left(T^{Re}_{\max}\right) \quad \text{or} \quad G\left(T^{Di}_{\max}\right) \subseteq G\left(T^{Re}_{\max}\right) \quad \text{or}$$
$$G\left(T^{Di}_{\max}\right) \supseteq G\left(T^{Re}_{\max}\right).$$

If $G\left(T^{Di}_{\max}\right) = G\left(T^{Re}_{\max}\right)$, then $G(T^{Th})$ is the perfect directed graph for the impact- relations map with both the maximum mean de-entropy dispatch-node set and receive-node set. If $G\left(T^{Di}_{\max}\right) \subseteq G\left(T^{Re}_{\max}\right)$ or $G\left(T^{Di}_{\max}\right) \supseteq G\left(T^{Re}_{\max}\right)$, then the structured $G(T^{Th})$ is the minimum impact-relations map which includes the necessary maximum mean de-entropy dispatch- and receive-node sets.

Based on $\boldsymbol{T}^{\text{example}}$, the results from Steps 1 to 6 are shown in Table 1.

4. Numerical case of the semiconductor intellectual property mall

In this section, a real case is shown by using the maximum mean de-entropy algorithm to set the threshold value. The original threshold value was determined through discussions with experts. By using the maximum mean de-entropy algorithm, the threshold value is different from the original result, but the impact-relations maps from these two threshold values are similar.

4.1. The semiconductor intellectual property mall case

SIP design, a new industry, is rapidly growing, which challenges both providers and users to develop infrastructure and standard interfaces. Establishing an SIP mall to provide a full array of SIP business services is a new concept used to promote growth of the SIP industry. Many foundries and governments have been involved in setting up SIP malls; however, the major services needed for an SIP mall to attract SIP providers and users must be clarified.

After we discussed and revised the questionnaire with experts, eighteen interrelated services, denoted from x_1 to x_{18}, were included in the final questionnaire. Twenty-four companies agreed to answer the questionnaire and discuss their responses. These 24 companies were experienced as licensees and licensors in the SIP business and had extensive knowledge about SIP trading and licensing. The DEMATEL method was used to discover and illustrate the key services needed to attract SIP users and providers to an SIP mall. Next, a total relation matrix was obtained from the nineteen 18 $\times$ 18 weighted matrices, shown in Fig. 4.

Based on the matrix $\boldsymbol{T}$, the maximum threshold value that allowed all services to be displayed on the impact-relations map was 0.36. When the threshold value increased to 0.45, only two direct relationships existed. The threshold value was determined by raising the threshold value from 0.36 to 0.45 in increments of 0.01 and conferring with experts in order to determine the optimal value to sufficiently display the interrelationships among these services. The threshold value was then set at 0.42, and the structured impact-relations map is shown in Fig. 5.

4.2. Maximum mean de-entropy algorithm results

Following the steps in Section 3.3, we obtained the results shown below:

Step 1: After transforming the total relation matrix $\boldsymbol{T}$, shown in Fig. 4, the ordered triplets set T^{*} was obtained as {(0.4612, 13, 14), (0.4587, 1, 14), (0.4489, 15, 14), (0.4357, 1, 13),(0.4355, 13, 17),..., (0.2051, 2, 2)}.

Step 2: According to the results of Step 1, the ordered dispatch-node set T^{Di} can be derived as {13, 1, 15, 1, 13, 16,..., 7, 4, 6, 7, 7, 2}.

Table 1
The results from Step 1 to Step 6.

Item	Data
Step 1: The ordered triplets set $T^{*\text{example}}$	{(0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), (0.0729, 3, 2), (0.0547, 5, 3), (0.0538, 1, 3), (0.0532, 5, 1), (0.0532, 5, 4), (0.0531, 4, 3), (0.0523, 1, 4), (0.0517, 2, 5), (0.0509, 3, 1), (0.0341, 3, 5), (0.0340, 4, 2), (0.0313, 4, 1), (0.0299, 3, 4), (0.0292, 2, 3), (0.0284, 2, 1), (0.0284, 2, 4), (0.0150, 5, 5), (0.0126, 1, 2), (0.0093, 1, 1), (0.0087, 3, 3), (0.0086, 4, 4), (0.0077, 2, 2)}
Step 2: Dispatch-node set, T^{Di}	{1, 5, 4, 3, 5, 1, 5, 5, 4, 1, 2, 3, 3, 4, 4, 3, 2, 2, 2, 5, 1, 1, 3, 4, 2}
Step 3.1: T^{Di}_t sets and MDE^{Di}_t values	$T^{Di}_1 = \{1\},\ MDE^{Di}_1 = 0;\ T^{Di}_2 = \{1,5\},\ MDE^{Di}_2 = 0;\ T^{Di}_3 = \{1,5,4\},\ MDE^{Di}_3 = 0;\ T^{Di}_4 = \{1,5,4,3\},\ MDE^{Di}_4 = 0;\ T^{Di}_5 = \{1,5,4,3,5\},\ MDE^{Di}_5 = 0.0135; \ldots,$ $T^{Di}_{25} = \{1, 5, 4, 3, 5, 1, 5, 5, 4, 1, 2, 3, 3, 4, 4, 3, 2, 2, 2, 5, 1, 1, 3, 4, 2\}, MDE^{Di}_{25} = 0;$
Step 3.2: Set of 25 MDE^{Di}_t values	{0, 0, 0, 0, 0.0135, 0.0142, 0.0273, 0.0433, 0.0283, 0.0266, 0.0283, 0.0185, 0.0169, 0.0145, 0.0160, 0.0165, 0.0060, 0.0019, 0.0012, 0.0025, 0.0009, 0.0012, 0.0012, 0.0007, 0}
Step 4.1: Maximum MDE^{Di}_t	0.0433
Step 4.2: Dispatch-node set of maximum MDE^{Di}_t	{1, 5, 4, 3, 5, 1, 5, 5} = {1, 3, 4, 5}
Step 5.1:Receive-node set, T^{Re}	{5, 2, 5, 2, 3, 3, 1, 4, 3, 4, 5, 1, 5, 2, 1, 4, 3, 1, 4, 5, 2, 1, 3, 4, 2}
Step 5.2: Set of 25 MDE^{Re}_t values	{0, 0, 0.0283, 0, 0.0146, 0, 0.0086, 0.0099, 0.0173, 0.0105, 0.0126, 0.0041, 0.0089, 0.0071, 0.0045, 0.0015, 0.0020, 0.0019, 0.0012, 0.0025, 0.0009, 0.0012, 0.0012, 0.0007, 0}
Step 5.3:Maximum MDE^{Re}_t	0.0283
Step 5.4: Receive-node set of the maximum MDE^{Re}_t	{5, 2, 5}= {2, 5}
Step 6.1:$T^{Di}_{\max}$	{(0.0759, $\boxed{1}$, 5), (0.0758, $\boxed{5}$, 2), (0.0752, $\boxed{4}$, 5), (0.0729, $\boxed{3}$, 2)} (the nodes in shaded box is the needed dispatch-nodes shown at first time in the ordered set)
Step 6.2: $T^{Re}_{\max}$	{(0.0759, 1, $\boxed{5}$), (0.0758, 5, $\boxed{2}$)} (the nodes in shaded box is the needed receive-nodes shown at first time in the ordered set)
Step 6.3: T^{Th}	{(0.0759, 1, 5), (0.0758, 5, 2), (0.0752, 4, 5), (0.0729, 3, 2)}
Step 6.4: Threshold value	0.0729

$T =$

0.3416	0.2946	0.3938	0.3161	0.3927	0.3936	0.3230	0.3736	0.4252	0.3969	0.4188	0.3984	0.4357	0.4587	0.4328	0.4192	0.4185	0.3791
0.2903	0.2051	0.2991	0.2688	0.3025	0.2889	0.2546	0.2929	0.3411	0.3124	0.3223	0.3175	0.3369	0.3644	0.3169	0.3211	0.3342	0.2947
0.3741	0.2745	0.3136	0.3129	0.3604	0.3454	0.3103	0.3714	0.4148	0.3708	0.3990	0.3735	0.4201	0.4162	0.4056	0.3809	0.3941	0.3690
0.3153	0.2693	0.3099	0.2399	0.3263	0.3067	0.2781	0.3164	0.3556	0.3362	0.3645	0.3401	0.3579	0.3846	0.3447	0.3338	0.3602	0.3058
0.3167	0.2488	0.2980	0.2663	0.2637	0.2932	0.2558	0.2965	0.3411	0.3132	0.3346	0.3192	0.3363	0.3535	0.3389	0.3213	0.3422	0.3011
0.3221	0.2331	0.2879	0.2567	0.2863	0.2491	0.2570	0.2869	0.3210	0.3105	0.3190	0.3153	0.3338	0.3477	0.3278	0.3259	0.3266	0.2911
0.2748	0.2178	0.2815	0.2428	0.2709	0.2754	0.2069	0.2743	0.3107	0.2981	0.3206	0.2879	0.3139	0.3333	0.3122	0.3191	0.3111	0.2728
0.3195	0.2547	0.3392	0.2739	0.3172	0.3035	0.2629	0.2760	0.3732	0.3335	0.3511	0.3392	0.3736	0.3865	0.3650	0.3643	0.3619	0.3308
0.3562	0.2713	0.3646	0.3039	0.3585	0.3294	0.2889	0.3460	0.3349	0.3683	0.3883	0.3700	0.4029	0.4222	0.3909	0.3777	0.3892	0.3454
0.3336	0.2561	0.3102	0.2779	0.3311	0.3204	0.2813	0.3138	0.3511	0.2900	0.3501	0.3361	0.3594	0.3823	0.3678	0.3636	0.3651	0.3227
0.3609	0.2765	0.3496	0.3203	0.3348	0.3456	0.2960	0.3346	0.3776	0.3509	0.3209	0.3493	0.3876	0.4092	0.3764	0.3767	0.3717	0.3396
0.3177	0.2517	0.3022	0.2636	0.3077	0.2953	0.2513	0.2993	0.3280	0.3120	0.3194	0.2705	0.3434	0.3535	0.3350	0.3286	0.3414	0.3014
0.4116	0.3088	0.4023	0.3420	0.3997	0.3820	0.3356	0.3816	0.4312	0.4067	0.4263	0.4029	0.3774	0.4612	0.4313	0.4265	0.4355	0.3826
0.3395	0.2762	0.3231	0.2984	0.3443	0.3293	0.2807	0.3319	0.3754	0.3548	0.3565	0.3511	0.3639	0.3410	0.3641	0.3797	0.3831	0.3287
0.4075	0.2951	0.3902	0.3194	0.3890	0.3746	0.3340	0.3824	0.4213	0.4022	0.4060	0.3932	0.4304	0.4490	0.3672	0.4266	0.4329	0.3964
0.3815	0.2979	0.3648	0.3174	0.3685	0.3688	0.3373	0.3664	0.3950	0.3807	0.3856	0.3700	0.3971	0.4351	0.4116	0.3440	0.4061	0.3553
0.3205	0.2582	0.3098	0.2774	0.3208	0.2995	0.2600	0.3072	0.3434	0.3305	0.3298	0.3268	0.3449	0.3702	0.3483	0.3423	0.2985	0.3037
0.3656	0.2653	0.3539	0.2946	0.3595	0.3346	0.2944	0.3392	0.3867	0.3535	0.3683	0.3550	0.3869	0.4028	0.3851	0.3723	0.3766	0.2936

Fig. 4. The total relation matrix of the SIP mall case.

- ***Step 3***: Based on the set T^{Di}, a collection of sets T_t^{Di}, in which t is from 1 to 324, can be obtained. After we calculate all of the H^D values of the sets T_t^{Di}, we can obtain a set with 324 mean de-entropy values, $\{0, 0, 0, 0.0196, 0.0146, 0.0142, \ldots, 0, 0, 0\}$, shown in Fig. 6.
- ***Step 4***: Within the set obtained in Step 3, the maximum mean de-entropy value is 0.0485 and the corresponding dispatch-node set is $\{13, 1, 15, 1, 13, 16, 15, 1, 13, 13, 15, 15, 13, 13, 1, 9, 15, 3, 1, 1, 1\}$.
- ***Step 5***: Similar to Steps 2–4, the ordered receive-node set T^{Re}, the de-entropy value set of T^{Re}, a maximum mean de-entropy value, and corresponding receive-node set $T^{Re}_{\max}$ are shown in Fig. 7 and Table 2.
- ***Step 6***: According to the results of Steps 4 and 5, the elements $\{1, 3, 9, 13, 15, 16\}$ must be the dispatch-nodes and the elements $\{13, 14, 17\}$ must be the receive-nodes in the impact-relations map. Based on these two constraints, the needed subset, T^{Th}, of the ordered set T^* is $\{(0.4612, \boxed{13}, \boxed{14}), (0.4587, \boxed{1}, 14), (0.4490, \boxed{15}, 14), (0.4357, 1, \boxed{13}), (0.4355, 13, \boxed{17}), (0.4351, \boxed{16}, 14), (0.4329, 15, 17), (0.4328, 1, 15), (0.4313, 13, 15), (0.4312, 13, 9), (0.4304, 15, 13), (0.4266, 15, 16), (0.4265, 13, 16), (0.4263, 13, 11), (0.4252, 1, 9), (0.4222, \boxed{9}, 14), (0.4213, 15, 9), (0.4201, \boxed{3}, 13)\}$. In above set T^{Th}, the nodes in the shaded box are the needed dispatch-nodes shown the first time in the ordered set T^{Th}, the nodes in the non-shaded box are the needed dispatch-nodes shown the first time in the ordered set T^{Th}, and the minimum influence value in T^{Th} is the threshold value, 0.4201.

Based on the subset obtained in Step 6, the threshold value could be determined as 0.4201 and then the impact-relations map can be structured. In this case, the impact-relations map derived from the MMDE algorithm is same as that shown in Fig. 5.

4.3. Discussion

The premise of the DEMATEL method is that the factors are not totally pair-wise independent. One important reason for using the DEMATEL method to solve a specific problematique is to understand the interrelations between factors and expressing the relationships in a directed graph. If all information in the *total relation matrix* is displayed in the impact-relations map, then the impact-relations map is defined as a "complete graph" in graph

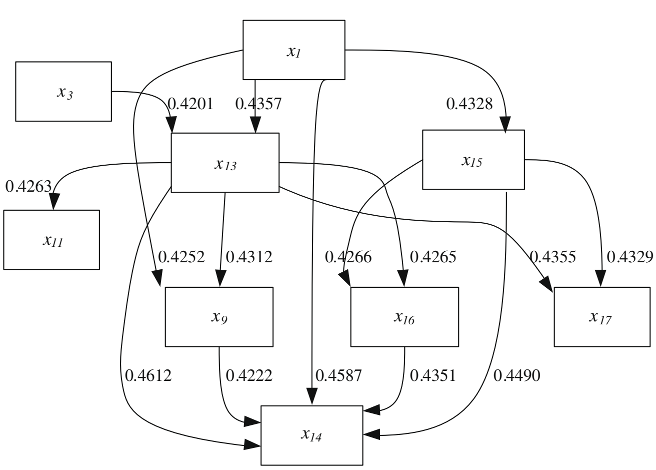

Fig. 5. Impact-relations map based on the threshold value $p = 0.42$.

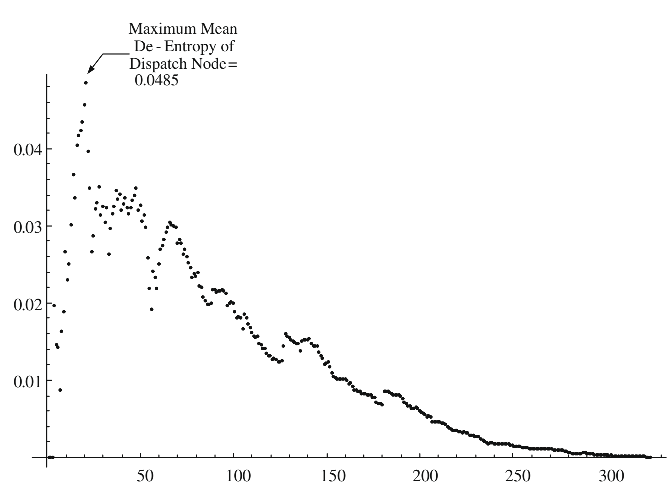

Fig. 6. 324 mean de-entropy values with a maximum mean de-entropy value of 0.0485.

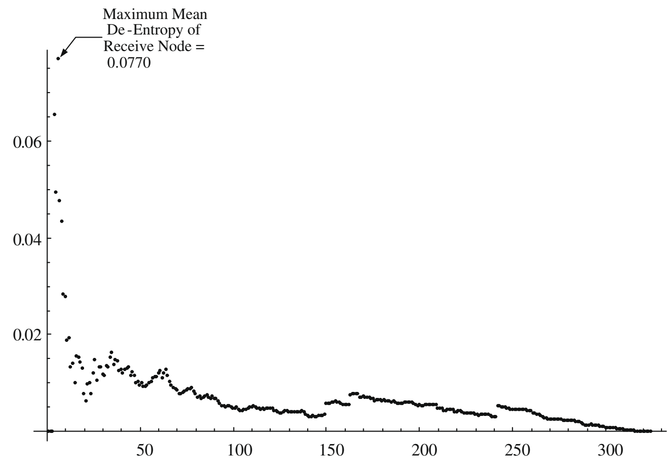

Fig. 7. 324 mean de-entropy values of receive-nodes set with a maximum mean de-entropy value of 0.0770.

theory, and every distinct vertex is connected by an edge. For a decision maker, this is no better than a situation which has no information. Another purpose for using DEMATEL is to avoid too much useless information. Selecting an adequate threshold value to judge whether a relation is obvious is a key question for the DEMATEL method. The proposed MMDE algorithm has some properties that differ from the traditional method to make the threshold value, as discussed below.

4.3.1. The MMDE mainly serves to decide the "node" rather than the "map"

Using traditional methods, the main issue of discussion is whether a "map" is suitable to the problematique after a threshold value is set. In traditional methods, the researcher set a subject adequate threshold to draw the impact-relations map and discussed it with experts to obtain a consistent opinion. If experts are not in agreement on the results, the researcher increases or decreases the threshold value to create another impact-relations map and again discusses it with experts until a consistent impact-relations map is accepted by experts and the final threshold value is set. In the SIP mall example, the traditional method involves finding a "suitable" threshold value, 0.36, and then raising the threshold value from 0.36 to 0.45 in increments of 0.01 and conferring with experts about the impact-relations map corresponding to each value, finally determining the optimal value to be 0.42.

In the proposed MMDE, the main issue is about whether it is suitable to add a new "node". If adding a new node can improve the "mean de-entropy", then adding it can be helpful to understand a problematique by decreasing the uncertainty of information. Using MMDE, we first decide that the nodes 1, 3, 9, 13, 15 and 16 have to be the dispatch-nodes in the impact-relations map while the nodes 13, 14, and 17 have to be the receive-nodes in the map, and then set the threshold value at 0.4201. The processes and results for these two methods are different, but the impact-relations maps are same. This means that MMDE is a suitable method to determine a threshold value in the first, or the final, step in order to discuss the adequacy of the impact-relations map.

4.3.2. The MMDE considers the properties of both the dispatch and receive influences of a factor

In the DEMATEL method, after a suitable map is obtained, the focus of the problem can be shown by analyzing the values $w(_i$ and v_i, as formulas (5) and (6), of the factors in the map. The value $(w_i + v_i)$—the index representing the strength of the influence of both dispatched and received—shows the central role that factor *i* plays in the problem. Commonly, a higher $(w_i + v_i)$ value means that the factor has a stronger connection with the other factors and plays a central role. A higher $(w_i - v_i)$ value means that this factor has a stronger influence *on* other factors than the influence it *receives* from them. If $(w_i - v_i)$ is positive, then factor *i* is

Table 2
The results derived from Steps 2 to 6 using the MMDE algorithm.

Item	Data
Receive-node set, T^{Re}	{14, 14, 14, 13, 17, 14, 17, 15, 15, 9, 13, 16, 16, 11, 9, 14, 9, 13, 16, 11,17, 14, 9, 1, 15, 14, 1, 10, 17, 15, 11, 13, 3, 12, 14, 10, 5, 11, 12, 18, 10, 13, 9, 6, 3, 17, 5, 12, 15, 3, 17, 5, 11, 13, 9, 13, 14, 15, 11, 14, 17, 8, 18, 14, 6, 1, 8, 10, 16, 16, 18, 9, 16, 16, 17, 15, 9, 6, 13, 1, 13, 9, 12, 8, 16, 8, 17, 10, 14, 12, 12, 18, 6, 5, 10, 15, 11, 8, 1, 11, 17, 15, 3, 14, 3, 16, 15, 16, 15, 13, 17, 1, 17, 5, 5, 13, 5, 13, 11, 1, 9, 10, 18, 12, 3, 14, 10, 14, 12, 11, 9, 10, 11, 3, 12, 15, 14, 6, 8, 18, 6, 13, 5, 15, 13, 9, 17, 16, 4, 17, 9, 16, 9, 12, 3, 18, 12, 8, 1, 15, 1, 7, 14, 13, 10, 13, 12, 7, 15, 11, 6, 8, 7, 17, 5, 13, 1, 14, 10, 16, 9, 8, 5, 18, 10, 11, 6, 6, 18, 16, 15, 9, 12, 5, 17, 16, 1, 18, 7, 3, 11, 11, 4, 5, 16, 16, 9, 6, 1, 16, 12, 11, 11, 1, 4, 11, 1, 12, 4, 1, 5, 8, 15, 12, 4, 1, 13, 8, 10, 4, 10, 15, 10, 3, 17, 9, 10, 7, 3, 3, 3, 2, 5, 8, 6, 18, 4, 18, 6, 5, 3, 18, 18, 8, 6, 3, 4, 10, 2, 3, 8, 17, 7, 6, 2, 18, 7, 4, 2, 6, 8, 18, 18, 1, 6, 7, 12, 10, 3, 8, 5, 7, 3, 7, 7, 4, 4, 2, 2, 6, 8, 1, 2, 8, 4, 18, 2, 5, 2, 4, 12, 4, 2, 4, 7, 5, 7, 2, 7, 4, 2, 7, 7, 2, 2, 7, 2, 6, 4, 4, 2, 2, 7, 2}
Mean de-entropy value set of T^{Re}	{0, 0, 0, 0.0654, 0.0494, 0.0770, 0.0476, 0.0433, 0.0283, 0.0277, 0.0187, 0.0193, 0.0133, 0.0141, 0.0099, 0.0156, 0.0152, 0.0143, 0.0130, 0.0078, 0.0063, 0.0098, 0.0099, 0.0077, 0.0119, 0.0149, 0.0106, 0.0133, 0.0132, 0.0117, 0.0114, 0.0135, 0.0133, 0.0153, 0.0163, 0.0139, 0.0147, 0.0145, 0.0125, 0.0128, 0.0119, 0.0128, 0.0130, 0.0133, 0.0115, 0.0123, 0.0116, 0.0101, 0.0102, 0.0095, 0.0099, 0.0092, 0.0093, 0.0096, 0.0101, 0.0103, 0.0111, 0.0112, 0.0114, 0.0121, 0.0124, 0.0110, 0.0120, 0.0128, 0.0115, 0.0102, 0.0095, 0.0091, 0.0087, 0.0085, 0.0078, 0.0079, 0.0080, 0.0083, 0.0084, 0.0087, 0.0088, 0.0090, 0.0082, 0.0078, 0.0070, 0.0073, 0.0069, 0.0071, 0.0072, 0.0075, 0.0070, 0.0067, 0.0072, 0.0069, 0.0067, 0.0062, 0.0058, 0.0053, 0.0051, 0.0051, 0.0051, 0.0053, 0.0050, 0.0047, 0.0048, 0.0050, 0.0045, 0.0042, 0.0042, 0.0045, 0.0046, 0.0048, 0.0049, 0.0050, 0.0052, 0.0050, 0.0046, 0.0048, 0.0046, 0.0047, 0.0046, 0.0048, 0.0048, 0.0046, 0.0047, 0.0043, 0.0042, 0.0040, 0.0037, 0.0037, 0.0039, 0.0041, 0.0041, 0.0040, 0.0041, 0.0041, 0.0041, 0.0039, 0.0039, 0.0040, 0.0042, 0.0039, 0.0035, 0.0033, 0.0030, 0.0031, 0.0032, 0.0031, 0.0031, 0.0032, 0.0033, 0.0033, 0.0034, 0.0058, 0.0057, 0.0058, 0.0059, 0.0060, 0.0062, 0.0061, 0.0059, 0.0058, 0.0056, 0.0055, 0.0054, 0.0055, 0.0075, 0.0076, 0.0078, 0.0077, 0.0077, 0.0070, 0.0071, 0.0072, 0.0071, 0.0071, 0.0069, 0.0067, 0.0068, 0.0063, 0.0064, 0.0064, 0.0064, 0.0063, 0.0065, 0.0064, 0.0063, 0.0061, 0.0061, 0.0061, 0.0060, 0.0059, 0.0058, 0.0058, 0.0058, 0.0059, 0.0059, 0.0060, 0.0059, 0.0060, 0.0058, 0.0055, 0.0054, 0.0054, 0.0053, 0.0054, 0.0054, 0.0055, 0.0055, 0.0055, 0.0055, 0.0055, 0.0054, 0.0048, 0.0047, 0.0048, 0.0043, 0.0043, 0.0044, 0.0045, 0.0045, 0.0045, 0.0041, 0.0041, 0.0041, 0.0041, 0.0040, 0.0037, 0.0038, 0.0038, 0.0038, 0.0038, 0.0037, 0.0036, 0.0034, 0.0034, 0.0034, 0.0034, 0.0034, 0.0035, 0.0035, 0.0032, 0.0031, 0.0030, 0.0030, 0.0052, 0.0051, 0.0051, 0.0050, 0.0049, 0.0047, 0.0047, 0.0046, 0.0046, 0.0046, 0.0045, 0.0045, 0.0045, 0.0044, 0.0044, 0.0044, 0.0043, 0.0043, 0.0043, 0.0038, 0.0038, 0.0035, 0.0035, 0.0031, 0.0031, 0.0028, 0.0027, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0025, 0.0023, 0.0023, 0.0023, 0.0023, 0.0023, 0.0023, 0.0022, 0.0021, 0.0020, 0.0019, 0.0018, 0.0016, 0.0014, 0.0014, 0.0014, 0.0014, 0.0012, 0.0012, 0.0011, 0.0011, 0.0010, 0.0010, 0.0010, 0.0009, 0.0008, 0.0008, 0.0007, 0.0007, 0.0006, 0.0006, 0.0005, 0.0004, 0.0004, 0.0003, 0.0003, 0.0002, 0.0002, 0.0002, 0.0001, 0, 0, 0, 0, 0, 0, 0, 0, 0}
Maximum mean de-entropy value	0.0770
The receive-node set of the maximum mean de-entropy value	{14, 14, 14, 13, 17, 14}

influencing the other factors. Different $(w_i + v_i)$ and $(w_i - v_i)$ values will be explained along with the structure of the factors' effects.

Using the proposed MMDE, we search the nodes, including dispatch- and receive-nodes, simultaneously. The MMDE not only considers the factors which strongly influence others, but also the factors which are easily influenced by other factors. The results obtained through the proposed algorithm follow the goals of the DEMATEL in finding out the interrelationships of "important" factors for allocating resources efficiently.

4.3.3. The MMDE can obtain a unique threshold value

To create a total relation matrix, the threshold value is determined through discussions with respondents or subjectively by the researcher, so the threshold value may differ if the experts or the researcher change. In the traditional method, the researcher may determine the threshold value by decreasing the value (this will change the impact-relations map from simple to complex) or by increasing the value (this will change the impact-relations map from complex to simple), so the results of these two methods may different. If too many factors are included, the problematique becomes too complex. Using the MMDE, a researcher can obtain a unique threshold value, which is helpful to solve the problem a researcher confronts in regards to selecting a consistent threshold value.

5. Conclusions

In the DEMATEL process, an appropriate threshold value is important in order to obtain adequate information to delineate the impact-relations map for further analysis and decision-making. Until now, the threshold value has been determined through discussions with respondents or chosen subjectively by researchers. It is time-consuming to make a consistent decision on the threshold value, especially when the number of factors in the problematique makes it too difficult to discuss the adequacy of an impact-relations map. If the threshold is determined by the researcher alone, it is important to clarify how to choose the specific value. A theoretical method to aid in deciding the threshold value is necessary.

This paper proposed an MMDE algorithm to determine the threshold value. The MMDE uses the approach of entropy, but also uses two other measures for the stability of information: "de-entropy" and "mean de-entropy". MMDE is mainly used to decide whether a node is suitable to express in the impact-relations map. With this method, a unique threshold value can be obtained, solving the problem of choosing the threshold value in the traditional way. In the numerical example, we show that the results from the MMDE are the same as the traditional method.

In future research, we will aim to apply this algorithm to other areas in information science and data mining in order to measure "adequate information", especially when faced with concerns about "too much information to make a decision".

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