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An analysis of DEMATEL approaches for criteria interaction handling within ANP

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ABSTRACT

Majority of the Multiple-Attribute Decision Making (MADM) methods assume that the criteria are independent of each other, which is not a realistic assumption in many real world problems. Several forms of interactions among criteria might occur in real life situations so that more sophisticated/intelligent techniques are required to deal with particular needs of the problem under consideration. Unfortunately, criteria interaction concept is very little issued in the literature. It is still a very important and critical research subject for intelligent decision making within MADM. The present paper aims to put a step forward to fill this gap by depicting the general picture, which provides a classification of methods related to criteria interaction phenomenon, and discuss/review the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Analytical Network Process (ANP) hybridizations first time in the literature. DEMATEL and ANP hybridizations grab remarkable attention of decision analysis community in recent years and seem as one of the most promising approaches to handle criteria interactions in a MADM setting.

1. Introduction

Decision making is a ubiquitous human activity that occurs in life of every individual very often. People generally confront with decision situations in their social, personal or professional lives in which two or more alternatives are present. Generally, daily life problems are degraded into mono-criterion and outcomes are calculated intuitively. However, choosing the best alternative among the set of options considering multiple, incommensurate and contradictory criteria exceeds cognitive limitations of decision makers and becomes a complicated issue. Making right decisions against complex problems yields significant influences on the future of individuals or groups.

Multiple-Attribute Decision Making (MADM) deals with such complex problems with multiple and conflicting criteria. Many state of art methods are proposed in the literature for modeling and solving MADM problems such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Analytical Network Process (ANP) (Saaty, 1996), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang & Yoon, 1981), Elimination et Choice Translating Reality (ELECTRE) (Roy, 1990), VlseKriterijumska Optimizacija I Kompromisno Resenje technique (VIKOR) (Opricovic & Tzeng, 2004), Conjoint Analysis (Krantz, 1964; Verma & Pullman, 1998) etc. However, majority of the MADM methods assume that the criteria are independent of each other, which is not a realistic assumption in many real world problems (Baykasoğlu, Kaplanoğlu, Durmuşoğlu, & Şahin, 2013). Several forms of interactions among criteria might occur in real life problems so that more sophisticated/intelligent techniques are required to deal with particular needs of the problem under consideration. Unfortunately, the criteria interaction concept is very little issued in the literature. To the best of our knowledge, there is not any comprehensive study, encompassing different methodologies capable of handling criteria interactions, and their discussions in the literature. Only reviews of specific methods are available such as ANP. Separated studies in this field hinder us from drawing a comprehensive portray of the available tools and methods for modeling criteria interactions. In recent years, many model developments in the field of decision analysis are observed incorporating criteria interactions. One of the rapidly evolving areas is the hybridization of several techniques to overcome the restrictive assumptions such as criteria independence. Probably, hybrid techniques of Decision Making Trial and Evaluation Laboratory (DEMATEL) (Fontela & Gabus, 1976) and ANP possess the fastest growing number of papers. Despite the increasing number of applications, different ways of hybridization of DEMATEL and ANP are not well known. This is mainly due to the significant number of papers in the literature, which increases complexity and requires time consuming analysis.

In this paper, DEMATEL method, which is attracting many researchers in the field of decision analysis in recent years, and its

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hybridizations with ANP are thoroughly analyzed, and published papers are reviewed in detail. We also depict the classification of interaction terms, which clarifies the positions of the analyzed methods among the big universe of available methodologies.

The remainder of the paper is organized as follows: In Section 2 a bird's eye view of criteria interaction phenomenon in MADM is given; in Section 3 the hybrid DEMATEL and ANP methods are explained with the illustrative examples and related literature reviews are given; in Section 4 bibliometric analysis of the papers is given; finally paper concludes in Section 5. Also the overview and main steps of the ANP and DEMATEL methods are given in Appendix A and B respectively.

2. A bird's eye view of criteria interaction phenomenon

MADM provides plethora of distinct methodologies for analysis of particular class of problems. Despite the vast diversity of methodologies, one common assumption is still maintained in most of them, which is the independence of criteria. It is a commonsense that independence of criteria is not a realistic assumption in real life problems. In recent years, many methods appeared in the literature for modeling criteria interactions. However, the literature still lacks the overall and comprehensive view onto the criteria interactions in decision analysis in general. Furthermore, there is no consensus on the basic definitions of the interaction concepts in the literature. These concepts are not well defined nor well understood in depth. As a result, further research is required to give detailed analysis on how specific methods consider interactions.

Above raised issues motivated us to elucidate the concept of independence of criteria, and provide the state-of-the art methods for modeling and solving criteria interactions in decision making. Fig. 1 shows our novel classification scheme.

In the literature, there are thousands of papers with theoretical findings and real-world applications in the field of decision analysis. It is indeed very challenging to concretely categorize the interactions terms, which mostly gain their meaning in the context of the study. Also the concept of criteria interactions is discussed very fragmentally, discussions are absorbed in the particular research habitats, and they are not diffused across other disciplines. For that reason, we collected and analyzed over 500 papers and several books (searched via Web of Knowledge, Wiley Online Library, SpringerLink, ScienceDirect, IEEE Xplore, Google Scholar etc.) to come up with a novel classification scheme of criteria interactions, which provides logically acceptable and clear-cut perspective that can be easily understood by even non-experts. To avoid excessive complexity, we have chosen to employ a bird's eye view to cover almost all the methods, yet with generic perspective as much as possible.

According to our classification, criteria dependency and criteria interactivity are two distinct philosophies. The criteria dependency is divided into three sub-categories, which are structural dependency, causal dependency, and preferential dependency. The structural dependency is prevalent in AHP, ANP, and hierarchical TOPSIS (Kahraman, Ateş, Çevik, Gülbay, & Erdoan, 2007). Structural dependency implies the dominance and dependency relations in the structure of the criteria. For instance, making pairwise comparison and obtaining criteria weights require determination of the structure of the criteria a priori, implying which criterion or cluster influences the other criteria and/or clusters (including feedback). In the causal dependency, cause and effect relationships are the underlying distinctions of these methods. Causal maps (Armstrong, 2005; Montibeller & Belton, 2006), DEMATEL, Fuzzy Cognitive Map (FCM) (Kosko, 1986), Bayesian networks (Jensen & Nielsen, 2007), System Dynamics (Barlas, 2002; Santos, et al., 2002; Tesfamariam & Lindberg, 2005), Interpretive Structural Modeling (ISM) (Huang, Tzeng, & Ong, 2005; Sage, 1977) and Structural Equation Modeling (SEM) (Punniyamoorthy, Mathiyalagan, & Parthiban, 2011) techniques are used to model causal dependency in decision analysis. The third dependency type is the preferential dependency. In the preferential dependency, preference orders of alternatives are changed when the level of criteria are altered. In other words, the decision

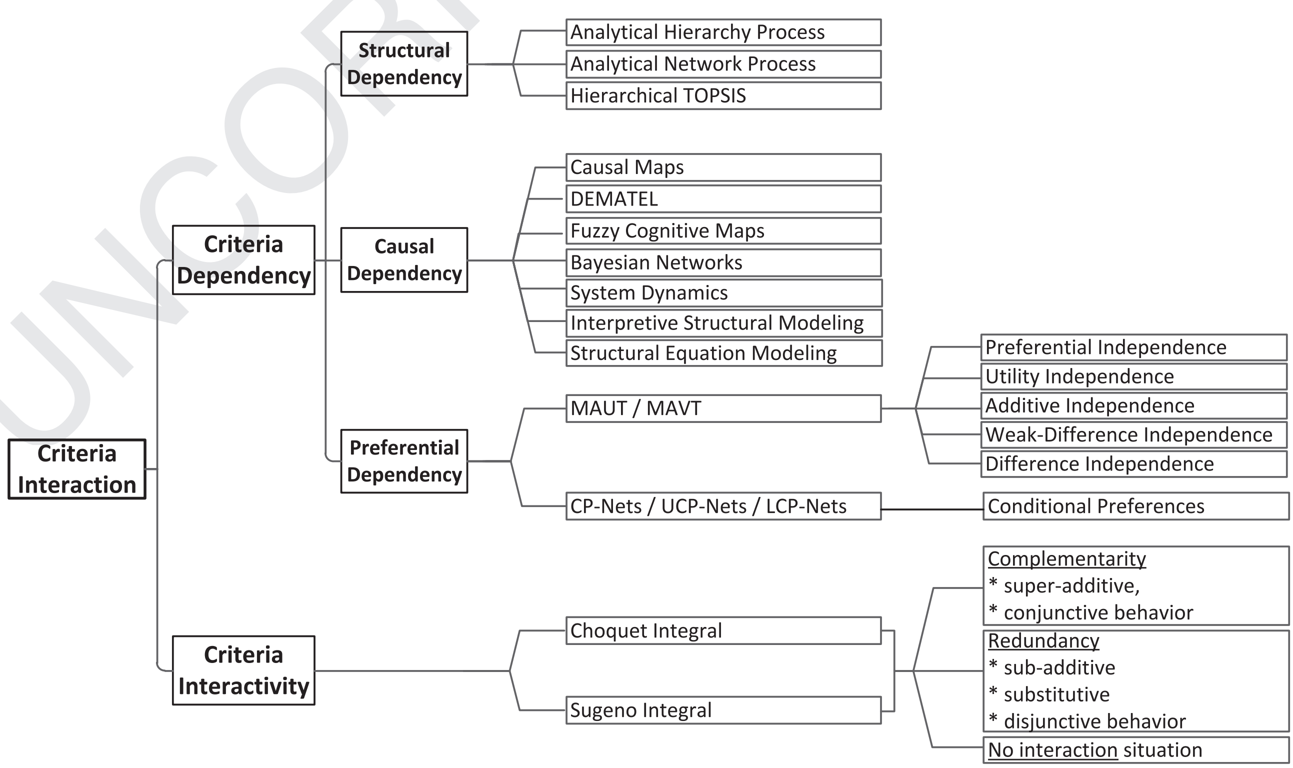

Fig. 1. A bird's eye view of criteria interaction phenomenon.

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maker's preference does indeed change when the level or state of a criterion is not remained unchanged. Multi Attribute Utility Theory (MAUT) (Fishburn, 1965, 1970; Winkler, 1990) and Multi Attribute Value Theory (MAVT) (Dyer, 2005; Salo & Hämäläinen, 1997) offers very detailed distinctions of independence concepts, namely preferential independence, utility independence, additive independence, weak-difference independence, and difference independence (Keeney, 1981). On the other hand, Conditional Preference Networks (CP-nets, also known as Ceteris Paribus Nets) (Boutilier, Brafman, Domshlak, Hoos, & Poole, 2004), Utility CP-nets (UCP-nets) (Craig, Fahiem, & Ronen, 2001), or Linguistic Conditional Preference Networks (LCP-nets) (Chatel, Truck, & Malenfant, 2010) employ conditional preferences, in which the preference of the decision maker is conditioned by the levels of preceding criteria in the preference graph, hence dependencies of the criteria are taken into account for the final preference of the decision maker.

On the other hand, criteria interactivity differs from the criteria dependency in terms of methodological and philosophical aspects. Merriam-Webster dictionary defines the word interactive as "mutually or reciprocally active". Longman dictionary of contemporary English defines it as "involving talking and working together". The word interactive is associated with the concept of togetherness. Interestingly enough, the Choquet (Grabisch & Labreuche, 2010; Marichal, 2004; Marichal, 2000) and Sugeno integrals (Dubois, Marichal, Prade, Roubens, & Sabaadin, 2001; Sugeno, 1974, 1977; Torra & Narukawa, 2006), also known as the members of non-additive integrals or fuzzy integrals, make use of fuzzy measures to assign the degree of importance to the criteria. An important feature of the fuzzy measures is that they assign importance degrees not only to criteria but also to the coalition of criteria. Accordingly, importance degree of a coalition is highly influenced by the members of it. For instance, a criterion may not be very important for decision maker, however when it is evaluated in the coalition, being assessed with the presence of other criteria might lead to get higher importance degrees or vice versa.

The bird's eye view of interaction phenomenon in Fig. 1 provides the general map of the state of the art methodologies vacant in the literature. However, it masks complicated hybrid techniques due to its generalization. In the literature, methods seen in Fig. 1 hybridized to solve particular problems very often. For instance, there are studies employing both Choquet integral and ANP, causal maps and Bayesian networks, ISM and AHP etc. Among these hybrid techniques to model criteria interactions, DEMATEL and ANP hybridization has become extremely popular in recent years. There is no doubt that ANP is the most preferred MADM method for modeling dependence and feedback situations. There are more than a thousand papers of ANP recorded in the SCOPUS databases since 2005. Despite it's by far popularity, ANP comes up with several difficulties in practice (Baykasoğlu & Gölcük, 2015). To overcome the rigors of modeling with ANP, researchers employed DEMATEL to escalate the modeling capabilities and support the ANP methodology for better functioning. As there is enormous number of ANP applications and steadily increasing number of DEMATEL papers in the literature, analyzing different hybrid techniques of ANP and DEMATEL methods is becoming a challenging task. This paper aims to answer why and how the DEMATEL method is combined with the ANP. A very detailed literature analysis is given.

3. Overview of DEMATEL and ANP methods

In recent years, there have been many applications of DEMATEL method in conjunction with ANP. As a powerful tool that enable modeling cause and effect relationships, applications of DEMATEL method have increased and many different variants of hybrid techniques have been proposed in the MADM context. Therefore, selection and use of appropriate hybrid technique becomes a complicated problem. Under these circumstances, we try to shed light on the different variants of ANP and DEMATEL hybridization, thus researchers might find appropriate method for their analysis. In this study, we have carefully analyzed 95 papers and compared the methodological differences by giving the brief literature and bibliometric analysis.

In Fig. 2, DEMATEL method among the causal dependency models and the position of DEMATEL and ANP applications in our proposed

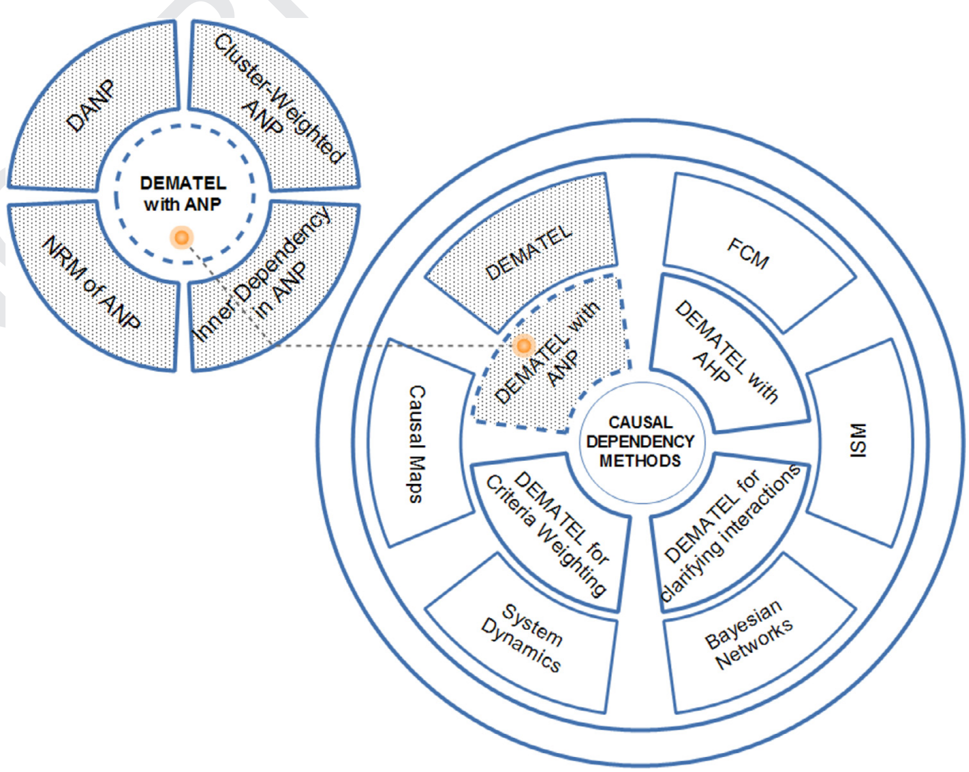

Fig. 2. DEMATEL with ANP Applications.

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Table 1
Comparison of hybridization categories.

Category	Criteria structuring	Inner dependency	Outer dependency	Weighting clusters
1. NRM of ANP	DEMATEL	ANP	ANP	ANP
2. Inner dependency of ANP	Expert opinion/DEMATEL	DEMATEL	ANP	ANP
3. Cluster-weighted ANP	DEMATEL	ANP	ANP	DEMATEL
4. DANP	DEMATEL	DEMATEL	DEMATEL	DEMATEL

framework have been shown. DEMATEL method is also used for clarifying interactions in decision models, finding criteria weights, and supporting decisions with AHP. In this paper, we only focused on the different usages of DEMATEL methods within ANP.

Despite the wide array of application variations, they can be grouped into four general categories as follows:

- Network Relationship Map (NRM) of ANP
- Inner Dependency in ANP
- Cluster-Weighted ANP
- DEMATEL-Based ANP (DANP)

The comparison table of the four different categories of DEMATEL and ANP hybrid techniques are summarized in Table 1.

The rationale behind the presented classification is that the DEMATEL method contributes to different components of the ANP for particular purposes. In its most general sense, an ANP study incorporates three important stages. They are drawing network structure of the problem, handling inner and outer dependencies via pairwise comparisons, and establishing the weighted supermatrix. The presented categorization is formed based on the published articles that deal with these stages in different ways.

Articles in the first category utilizes DEMATEL method merely for capturing NRM. Inner and outer dependencies are handled via ANP method, and weighted supermatrix is calculated based on traditional ANP weighting approaches as well. Articles in the second category deal with inner dependencies by using DEMATEL method. Criteria structuring can be established based on expert opinion or DEMATEL method. The outer dependencies and weighting of clusters are handled by using ANP method. The difficult pairwise comparison questions of ANP is the main motive of this type usage. The articles classified as the third category employ DEMATEL method for weighting of clusters and establishing NRM. Actually, the same total relation matrix is used for structuring and weighting. However, the main motive of this type of usage is incorporating the influence of unequal cluster weights into supermatrix formation. For instance, Yang and Tzeng (2011) entitled their method as "DEMATEL for a novel cluster-weighted with ANP method" to emphasize the main contribution of the method. Finally, articles in the fourth category adopts DEMATEL method for structuring criteria, handling inner and outer dependencies, and for weighting of clusters. In the literature, this type of hybridization is named DANP (Chen, Hsu, & Tzeng, 2011; Liu, Tzeng, & Lee, 2012).

3.1. Network relation map of ANP

In traditional AHP/ANP applications, it is assumed that the network structure of the decision problem is known a priori. However, this assumption does not comply with the real life situations where decision maker or analyst cannot form the problem structure easily. Specifically, utilizing ANP for complicated decision problems, the network structure is of vital importance in terms of accuracy of the model.

The ANP and AHP models quantify the influence between criteria based upon the pairwise comparisons. Additionally, pairwise comparisons are conducted with respect to problem structure. Here, we refer problem structure merely as relationships between criteria/clusters in the decision problem.

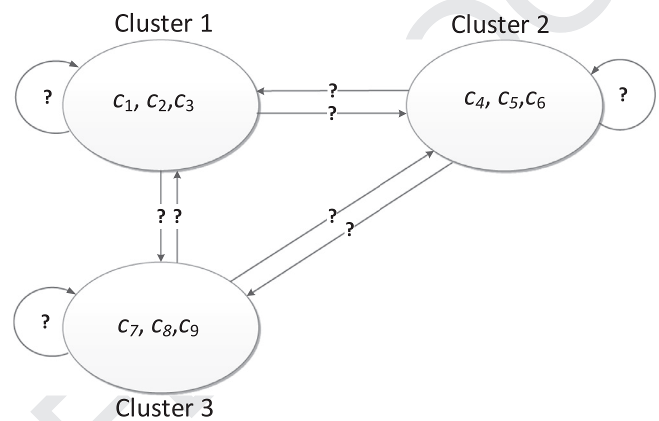

Fig. 3. Network diagram of Example 1.

Because of the substantial role of the relationships between criteria and clusters in ANP, DEMATEL method is applied to depict the NRM of the decision problem. This type of usage of DEMATEL method with ANP constitutes the highest proportion (in terms of number of published articles) in comparison with other hybrid techniques of ANP. Studies implementing DEMATEL method prior to ANP intends to:

- Determining the relationships between decision criteria/clusters.
- Making traditional pairwise comparisons with respect to NRM by which the DEMATEL method is used to construct.
- Utilizing some favorable features of the DEMATEL method such as visualizing cause and effect criteria, getting broader insight into relationships among criteria and clusters, and determining the most influential criteria and so on.

For the sake of increased understandability, examples are provided and hybrid techniques are explained in a step by step approach. The same example have been used throughout the paper in order to demonstrate the differences and similarities of the hybrid techniques.

Example 1. A decision problem involves three clusters and nine criteria. There are three criteria in each cluster. The semi-completed NRM of the problem is shown in Fig. 3. In order to carry out ANP method, one must know exactly whether the directed arrows indicated by question marks in Fig. 3 exist or not. Because the pairwise comparisons of the ANP are conducted based on the NRM, the first step should be to clarify the problem structure. In this sense, DEMATEL is a useful method to resolve the problem of establishing network structure. DEMATEL method helps to clarify the existence of directed arrows with question marks. Once the question marks in Fig. 3 are replaced by solid arrows, pairwise comparisons might be conducted to quantify relationships.

In Fig. 4, supermatrix representation regarding example 1 is provided. The partitions of the ANP structure can be seen as rectangles. $\boldsymbol{W}_{ij}$ is the priority vector of the influence of the elements compared in the jth cluster to the ith cluster. The local priority of criterion c_i with regard to c_j is represented by w_{ij}. Definitions and procedural steps of the ANP are given in Appendix A.

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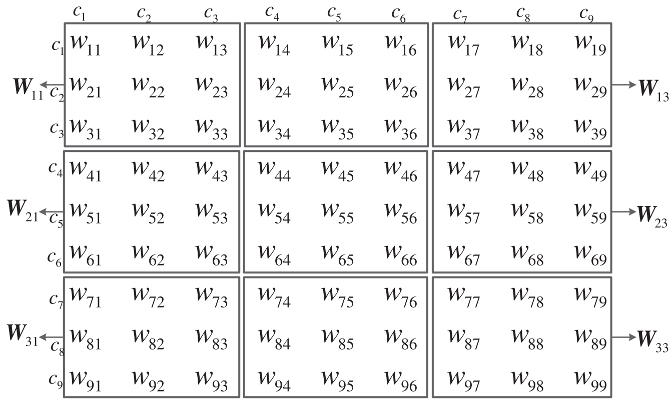

Fig. 4. Supermatirx representation of Example 1.

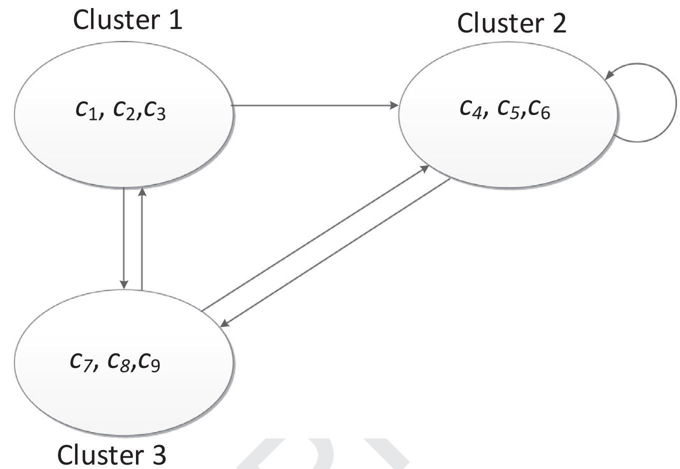

Fig. 5. Resulting network diagram of Example 1 after DEMATEL.

In order to determine the criteria structure, it is assumed that only one decision maker evaluates the assessment matrix and non-fuzzy scores are used for simplicity. Three clusters are compared to each other and initial direct relation matrix is formed. Following the procedural steps of the DEMATEL method given in Appendix B, total relation matrix is calculated. Then, setting a threshold value, minor impacts are omitted from the total relation matrix. The total relation matrix is calculated as given in Eq. 1.

$$\boldsymbol{T}_D = \begin{bmatrix} 0 & 0.96 & 0.55 \\ 0 & 0.52 & 0.80 \\ 0.2 & 0.60 & 0 \end{bmatrix} \tag{1}$$

where $\boldsymbol{T}_D$ represents the total relation matrix for clusters. Accordingly, the resulting network structure is drawn as shown in Fig. 5.

The resulting supermatrix is shown in Fig. 6. The non-zero entries are required to be filled out by pairwise comparison results of the ANP method.

According to first category of this study, the presented papers utilize DEMATEL for only constructing NRM. For instance, unweighted and weighted supermatrices are constructed based on the traditional ANP procedures. To be able to make comparisons with the other approaches that will be presented in subsequent sections, suppose that the unweighted supermatrix is constructed as given in Eq. 2.

$$\boldsymbol{W} = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \end{array} \\ \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 & 0.58 & 0.28 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.60 & 0.22 & 0.46 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 & 0.20 & 0.26 \\ 0.60 & 0.51 & 0.31 & 0.50 & 0.33 & 0.16 & 0.44 & 0.35 & 0.44 \\ 0.20 & 0.37 & 0.41 & 0.32 & 0.40 & 0.62 & 0.15 & 0.30 & 0.36 \\ 0.20 & 0.12 & 0.28 & 0.18 & 0.27 & 0.22 & 0.41 & 0.35 & 0.20 \\ 0.13 & 0.27 & 0.41 & 0.25 & 0.32 & 0.20 & 0.00 & 0.00 & 0.00 \\ 0.21 & 0.63 & 0.42 & 0.23 & 0.46 & 0.30 & 0.00 & 0.00 & 0.00 \\ 0.66 & 0.10 & 0.17 & 0.52 & 0.22 & 0.50 & 0.00 & 0.00 & 0.00 \end{bmatrix} \end{array} \tag{2}$$

Assuming the equal cluster weights, weighted supermatrix can be calculated by ensuring that the columns sum to unity. The weighted supermatrix is given in Eq. 3.

$$\boldsymbol{W} = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \end{array} \\ \begin{bmatrix} 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.100 & 0.290 & 0.140 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.300 & 0.110 & 0.230 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.100 & 0.100 & 0.130 \\ 0.300 & 0.255 & 0.155 & 0.250 & 0.165 & 0.080 & 0.220 & 0.175 & 0.220 \\ 0.100 & 0.185 & 0.205 & 0.160 & 0.200 & 0.310 & 0.075 & 0.150 & 0.180 \\ 0.100 & 0.060 & 0.140 & 0.090 & 0.135 & 0.110 & 0.205 & 0.175 & 0.100 \\ 0.065 & 0.135 & 0.205 & 0.125 & 0.160 & 0.100 & 0.000 & 0.000 & 0.000 \\ 0.105 & 0.315 & 0.210 & 0.115 & 0.230 & 0.150 & 0.000 & 0.000 & 0.000 \\ 0.330 & 0.050 & 0.085 & 0.260 & 0.110 & 0.250 & 0.000 & 0.000 & 0.000 \end{bmatrix} \end{array} \tag{3}$$

3.1.1. Related review

Ho, Tsai, Tzeng, and Fang (2011) proposed a novel MADM model with DEMATEL, ANP, and VIKOR for a portfolio selection problem. The DEMATEL method was used for obtaining NRM. Based on NRM obtained by DEMATEL method, ANP was carried out to find the criteria weights. Finally, the most suitable investment was identified by VIKOR.

Chen and Tzeng (2011) constructed NRM of the teaching materials evaluation problem by using DEMATEL method. Then pairwise comparisons by using Saaty's 1–9 scale were conducted based on the NRM, and the obtained weights were placed into the supermatrix of ANP . An empirical study of Mandarin Chinese teaching materials was provided.

Lin, Hsieh, and Tzeng (2010) proposed a model based on the DEMATEL, ANP and TOPSIS methods for evaluating vehicle telematics systems. The DEMATEL method was used to construct the NRM of criteria. Based on the NRM obtained by DEMATEL method, ANP was applied to obtain the relative weights of dependent criteria. Finally, TOPSIS method was implemented to determine the most appropriate VTS product.

$$\begin{array}{cc|ccc|ccc|ccc|c}
 & & c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 & \\
\hline
 & c_1 & 0 & 0 & 0 & 0 & 0 & 0 & w_{17} & w_{18} & w_{19} & \\
\mathbf{W}_{11} \leftarrow & c_2 & 0 & 0 & 0 & 0 & 0 & 0 & w_{27} & w_{28} & w_{29} & \rightarrow \mathbf{W}_{13} \\
 & c_3 & 0 & 0 & 0 & 0 & 0 & 0 & w_{37} & w_{38} & w_{39} & \\
\hline
 & c_4 & w_{41} & w_{42} & w_{43} & w_{44} & w_{45} & w_{46} & w_{47} & w_{48} & w_{49} & \\
\mathbf{W}_{21} \leftarrow & c_5 & w_{51} & w_{52} & w_{53} & w_{54} & w_{55} & w_{56} & w_{57} & w_{58} & w_{59} & \rightarrow \mathbf{W}_{23} \\
 & c_6 & w_{61} & w_{62} & w_{63} & w_{64} & w_{65} & w_{66} & w_{67} & w_{68} & w_{69} & \\
\hline
 & c_7 & w_{71} & w_{72} & w_{73} & w_{74} & w_{75} & w_{76} & 0 & 0 & 0 & \\
\mathbf{W}_{31} \leftarrow & c_8 & w_{81} & w_{82} & w_{83} & w_{84} & w_{85} & w_{86} & 0 & 0 & 0 & \rightarrow \mathbf{W}_{33} \\
 & c_9 & w_{91} & w_{92} & w_{93} & w_{94} & w_{95} & w_{96} & 0 & 0 & 0 & \\
\hline
\end{array}$$

Fig. 6. Resulting supermatirx representation of Example 1 after DEMATEL.

Kuo (2011) proposed a hybrid MADM framework based on fuzzy DEMATEL, fuzzy integral and TOPSIS for optimal location selection for an international distribution center. First, hierarchical/network structure was determined by using fuzzy DEMATEL method. Next, criteria weights were determined using AHP/ANP methods based on the NRM. Finally, fuzzy synthetic performance of each alternative was calculated by using TOPSIS and fuzzy integral.

Wu, Lin, and Chang (2011) developed a performance evaluation indices based on balanced scorecard, DEMATEL, ANP and VIKOR. DEMATEL method was employed for capturing interrelationships among balanced scorecard perspectives and constructing the NRM. Based on the DEMATEL analysis, ANP was used to obtain the criteria weights. Finally, obtained criteria weights were used by VIKOR method to rank the alternatives.

Tsai and Chou (2009) proposed DEMATEL, ANP and zero-one goal programming based method for selecting optimal management system. DEMATEL method was used to capture the interrelationships among criteria and draw the NRM. Based on the NRM obtained by DEMATEL, ANP was carried out to determine the priorities. Finally, the priority weights were incorporated into zero-one goal programming formulation to select the best alternative.

Chen and Chen (2010b) evaluated innovation performances of higher education institutions by DEMATEL, fuzzy ANP and TOPSIS methods. DEMATEL method was used to obtain total influence matrix regarding dimensions and to construct the NRM. Based on the NRM obtained from DEMATEL, FANP pairwise comparisons were performed and weights were calculated.

Tzeng and Huang (2011) proposed a novel MADM framework for selecting a global manufacturing strategy by considering both aspects of global manufacturing and logistics. The interrelationships between criteria were captured and the NRM was constructed by DEMATEL method. Secondly, based on the NRM obtained from DEMATEL, the weights of each criterion versus the goal of the MADM problem was derived by ANP. Then the priorities of global manufacturing and logistics system were ranked and selected by VIKOR method.

Tsai and Hsu (2010) presented a hybrid model based on DEMATEL and ANP for selecting cost of quality model. DEMATEL method was used to obtain criteria structure incorporating cause and effect relationships. Based on the criteria structure acquired from DEMATEL method, ANP method was utilized to select the optimal model.

Lo and Chen (2012) proposed a hybrid procedure for evaluating risk levels of information security under various security controls. The DEMATEL method was used to construct the interrelationships among security control areas and to obtain NRM. Based on the NRM derived from DEMATEL, the ANP method was applied to obtain the weights of criteria.

Liou, Wang, Hsu, and Yin (2011) proposed a new hybrid multiple criteria decision-making model by combining the DEMATEL method, ANP and fuzzy preference programming for outsourcing service provider selection in airline company. The DEMATEL method was used to capture the interrelationships among dimensions. Based on the NRM captured by the DEMATEL method, fuzzy preference programming based ANP method was applied to derive the weights of criteria.

Tsai, Chou, and Lai (2010) introduced a MADM approach combining the DEMATEL method, ANP and zero-one goal programming to form an optimal project task sourcing portfolio. Using the DEMATEL method, total relation matrices were constructed for perspectives and criteria to obtain NRM. Then, pairwise comparisons were employed to form unweighted supermatrix in accordance with the NRM.

Chen and Chen (2010a) proposed a pro-performance appraisal system for higher education in Taiwan by using the DEMATEL and fuzzy ANP. The level of interrelationships between the dimensions of the evaluation system was determined by DEMATEL. By setting a threshold value in total relation matrix, NRM was depicted. Then, the fuzzy ANP method was carried out and criteria were prioritized.

Hung (2011) conducted a five forces analysis and DEMATEL method was adopted to analyze interdependencies between five forces. When relationships among five forces were depicted by using DEMATEL method, ANP method was carried out in order to determine the weights of five forces.

Tsai et al. (2010) proposed an integrated model for evaluating websites in tourism industry by combining DEMATEL, ANP and modified VIKOR method. The DEMATEL method was used to capture the interrelationships among criteria and build a visual structural map. Then, ANP was used to obtain the relative weights of evaluation criteria. Next, the modified VIKOR method was used to rank the websites. The same methodology was applied by Tsai, Chou, and Leu (2011) for the web-based marketing of airline industry.

Tsai et al. (2010) integrated the DEMATEL, AHP, ANP, and zero-one goal programming methods to find an optimal corporate social responsibility programs in the international tourist hotel. The DEMATEL method was used to detect complex relationships among the cost and differentiation advantage related criteria. After the interdependencies were captured by DEMATEL, AHP and ANP methods were carried out to obtain criteria weights. Then, the AHP/ANP results were incorporated into zero-one goal programming formulation.

Lee and Tu (2011) proposed a hybrid MADM combining DEMATEL, ANP and VIKOR methods to explore company value based on Modigliani–Miller theorem. The influential relationships among criteria were captured by DEMATEL method. Based on the criteria structure obtained by DEMATEL, ANP was applied to derive criteria weights. Finally, VIKOR method was used to rank the companies.

Padhi and Aggarwal (2011) investigated the revenue management problem of a hotel industry by incorporating artificial neural networks, DEMATEL, ANP and fuzzy goal programming approaches. DEMATEL method was carried out to obtain network of criteria structure. Afterwards, ANP was used to acquire the dependent criteria weights. Finally, fuzzy goal programming approach was established in order to find optimal numbers of commodities in a hotel.

Liou and Chuang (2010) applied DEMATEL, ANP, and VIKOR methods for selection of outsourcing providers in airline industry. The dependent relationships among criteria were addressed by using DEMATEL method. Based on the criteria structure obtained by DEMATEL, relative weights of criteria were determined using ANP method. The VIKOR method was then used to rank the outsourcing providers.

Liou (2012) proposed a hybrid model combining DEMATEL, ANP, and fuzzy preference programming for selecting suitable partners for strategic alliances. DEMATEL method was used to construct the NRM of the interrelated criteria. Then, based on the NRM derived from DEMATEL, ANP method was carried out. Pairwise comparisons between criteria were conducted using fuzzy preference programming which deals with the ambiguity and vagueness in human judgments. The method was demonstrated using data from a Taiwanese airline.

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Tsai and Kuo (2011) integrated DEMATEL, ANP, and zero-one goal programming methods for evaluating entrepreneurship policies of small and medium sized enterprises. The DEMATEL method was used to grasp the network structure considering the causal interrelations. Then, ANP was applied in order to obtain weights of criteria. Finally, zero-one goal programming was constructed to select the best alternative.

Kuo and Liang (2011) proposed a novel hybrid decision making model for selecting a distribution center. A new structural model combining fuzzy grey relational analysis and DEMATEL method was introduced for the purpose of structuring the criteria. On the basis of criteria structure, criteria weights were determined by using fuzzy ANP and fuzzy AHP.

Chen and Chen (2012) established a network hierarchical feedback system to assess the performance measurement of universities in terms of integration to total quality management and innovation. In the study, DEMATEL method was adopted to depict NRM of the criteria involved in the measurement system. Then, fuzzy ANP and fuzzy AHP were used to evaluate measurement criteria and find the importance degrees.

Tsai, Yang, Leu, Lee, and Yang (2013) proposed a decision support model for the financial decisions of corporations using DEMATEL, ANP and goal programming. DEMATEL method was used to capture the NRM of the decision problem. Then ANP was used to obtain influential weights in accordance with the NRM obtained via DEMATEL. Ultimately, goal programming was used to make the final financial decision in subject to related financial constraints.

Lee and Lee (2013) analyzed innovation strategy of hospitals. DEMATEL method used to capture the NRM, and ANP was utilized to find the final weights criteria. In the study, three most important criteria were determined to establish operational quality indicators of physical therapies.

Zolfani and Ghadikolaei (2013) evaluated private universities using balanced scorecards, DEMATEL, ANP, and VIKOR methods. The cause and effect relationships among balanced scorecard perspectives were resolved via DEMATEL method. ANP method was used to derive relative importance of criteria. Finally, VIKOR method was adopted for ranking private universities.

Kremer and Akman (2013) evaluated product development process performance by using DEMATEL and ANP. DEMATEL method was used to construct cause and effect relationships between criteria. Then, pairwise comparisons were conducted to derive overall priorities by using ANP. The proposed model was applied in a group of machine manufacturers in Turkey.

Ölçer and Akyol (2014) developed a spreadsheet-based decision support tool for the international contractor rating. The decision support tools was intended to help construction firms in their new market entry decisions. DEMATEL method was used to construct NRM of the decision criteria. Based on the NRM, ANP was employed to determine contractor ratings.

Tavana, Khalili-Damghani, and Rahmatian (2014) integrated balanced scorecards, DEMATEL method, fuzzy ANP, and fuzzy data envelopment analysis in performance measurement of publicly held pharmaceutical companies. DEMATEL method was used to capture interdependencies among the balanced scorecards perspectives. The relative importance of criteria was determined by fuzzy ANP method. Finally, fuzzy data envelopment analysis was employed to calculate the efficiency scores of the decision making units.

Kabak (2013) combined fuzzy DEMATEL and fuzzy ANP methods for personnel selection problem. Interdependencies among evaluation criteria were resolved via fuzzy DEMATEL method. Fuzzy ANP method was used to calculate the weight of each criterion and rank the applicants.

Torabi, Soufi, and Sahebjamnia (2014) proposed a framework for conducting business impact analysis using fuzzy DEMATEL and ANP methods. Fuzzy DEMATEL method was used to structure critical functions of key products. ANP method was used to rank the functions. A case study in an automotive industry was provided.

Uygun et al. (2014) evaluated outsourcing providers for a telecommunication company using DEMATEL and fuzzy ANP methods. Fuzzy ANP method was used to rank the outsourcing alternatives on the basis of the cause and effect relationships obtained from DEMATEL method. Q3

Tsai et al. (2013) integrated DEMATEL, ANP and goal programming for corporate financial decisions under group decision making setting. DEMATEL method was used to structure the evaluation criteria. ANP was employed to derive priority weights. Goal programming was utilized to deal with quantitative financial constraints for reaching a group solution.

Lin (2015) assessed product positioning of vehicle telematics systems by using DEMATEL, principal component analysis, ANP, and VIKOR methods. DEMATEL method was used to construct the NRM. Principal component analysis was applied to categorize criteria based on their properties. The ANP method was used to determine the criteria weights, and VIKOR method was adopted to determine the product position.

Fetanat and Khorasaninejad (2015) proposed a hybrid approach by using fuzzy DEMATEL, fuzzy ANP and fuzzy ELECTRE methods for integrated energy planning and coastal management frameworks. Fuzzy DEMATEL method was used to clarify interactions among criteria. ANP was utilized to obtain relative weights of criteria based on the DEMATEL results. Finally, fuzzy ELECTRE method was adopted for selection of the best site of offshore wind farm.

Fazli, Kiani Mavi, and Vosooghidizaji (2015) identified main risks associated with the crude oil supply chain using DEMATEL and ANP method. Interdependencies among risk factors were analyzed via DEMATEL method. ANP was used to obtain relative importance of each risk based on the NRM of risks. Finally, the best response strategy to mitigate supply chain risk factors are determined.

Ju, Wang, and You (2014) evaluated emergency alternatives by using DEMATEL, ANP, and 2-tuple linguistic TOPSIS method. DEMATEL method was used to obtain NRM of the decision problem. ANP method was applied to calculate the weights of attributes. Finally, 2-tuple linguistic TOPSIS method was used to select the best emergency alternative.

Yeh and Huang (2014) integrated fuzzy DEMATEL and ANP to examine factors in determining wind farm location selection. Fuzzy DEMATEL method was adopted to find the dependencies among factors. ANP was applied to calculate the relative weight of each factor on the basis of NRM of the criteria.

Azizi, Malekmohammadi, Jafari, Nasiri, and Amini Parsa (2014) evaluated wind power plant sites by using ANP and DEMATEL methods. DEMATEL method was used to establish criteria relationships. Based on the relationships among criteria, ANP was used to determine criteria weights.

Ahmadi, Nilashi, and Ibrahim (2015) investigated organizational innovation adoption factors with respect to hospital information systems by using DEMATEL and ANP methods. The strength of interdependencies among criteria was tested by DEMATEL method. On the basis of the NRM, ANP method was adopted to reach the relative importance of the adoption factors. An empirical study was conducted in Malaysian public hospitals.

Rezaeian and Akbari (2015) proposed a fuzzy DEMATEL and fuzzy ANP based model for portfolio selection problem. Fuzzy DEMATEL method was used to clarify interdependencies among attributes, and the fuzzy ANP method was employed to select the best alternative. The proposed model was implemented in Tehran Stock Exchange.

3.2. Inner dependency of ANP

ANP manages dependency as inner and outer dependency based on its structure. Inner dependency refers to dependency within the

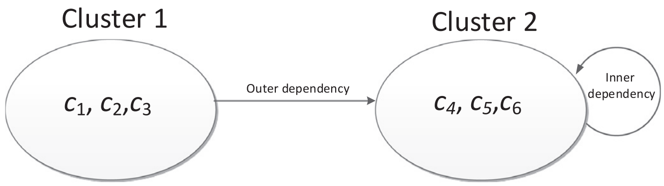

Fig. 7. Network diagram of Example 2.

cluster. If there is dependency among elements of different clusters, they are called outer dependency. In majority of the DEMATEL and ANP hybridizations, DEMATEL serves as a means of providing NRM of the problem. In addition to this, different approaches have been developed in order to benefit from DEMATEL for other purposes. Utilizing DEMATEL for handling inner dependency of the supermatrix is one of those innovative hybrid techniques.

In ANP, inner dependency, outer dependency, and self-feedback effects are all quantified by 9-scale pairwise comparisons. However, eliciting the required pairwise comparison information is not a trivial task. Yu and Tzeng (2006) emphasized the main shortcoming of ANP as (Baykasoğlu & Gölcük, 2015):

- ANP requires too many pairwise comparisons which might be time consuming and difficult to obtain
- For particular situations, pairwise comparison questions might be meaningless or difficult to interpret.

Especially, in the inner dependency situation the pairwise comparison questions can be nonsense. In what follows we explain why there is a need for DEMATEL for handling inner dependency, and related formulations will be given along with an example.

Example 2. Let us concentrate on a small portion of the Example 1 as seen in Fig. 7. To demonstrate that the pairwise comparison questions might be vague and meaningless, let us entitle the decision criteria. Suppose that we are evaluating mobile phone alternatives. Cluster 1 is named costs, and cluster 2 is designated as ergonomics. Criteria in cluster 1, denoted by c_1, c_2, c_3, are purchasing cost, maintenance cost, and accessory cost, respectively. On the other hand, criteria in cluster 2, denoted by c_4, c_5, $c_{6,}$ are referred as appearance, durability, and usability, respectively.

While conducting pairwise comparisons for modeling outer dependency, decision makers are asked to following questions:

- For the criterion of purchasing cost;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability
- For the criterion of maintenance cost;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability
- For the criterion of accessory cost;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability

Similarly, considering the inner dependencies, following pairwise comparison questions are asked for cluster 2:

- For the criterion of appearance;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability
- For the criterion of durability;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability
- For the criterion of usability;
  - How much more important the criterion of appearance than durability
  - How much more important the criterion of appearance than usability
  - How much more important the criterion of durability than usability

The first observation could be that the pairwise comparison questions for inner dependency are more challenging than those of the outer dependencies. Furthermore, decision makers, in many situations, cannot estimate that how much the criterion of appearance have the influence on the importance of appearance, durability and usability respectively. The same question might be asked in another form as; thinking of the criterion of appearance, which criterion is more important: appearance or durability? This question is absolutely nonsense even for domain experts. Accordingly, a need for another method for treating with the inner dependency of supermatrix is obvious.

One solution approach to the above mentioned problem is to obtain inner dependency matrix from DEMATEL method without using Saaty's pairwise comparisons. The total relation matrix obtained from DEMATEL method can be used as the inner dependency matrix in supermatrix.

Assume that the inner dependency matrix is obtained from DEMATEL method as given in Eq. 4.

$$\boldsymbol{T}_E = \begin{bmatrix} t_{11}^E & \cdots & t_{1j}^E & \cdots & t_{1n}^E \\ \vdots & & \vdots & & \vdots \\ t_{i1}^E & \cdots & t_{ij}^E & \cdots & t_{in}^E \\ \vdots & & \vdots & & \vdots \\ t_{n1}^E & \cdots & t_{nj}^E & \cdots & t_{nn}^E \end{bmatrix} \tag{4}$$

where $\boldsymbol{T}_E$ denotes the total relation matrix for inner dependency, and t_{ij}^E represents the degree of influence that the criterion i exerts on the criterion j. To be able to use this matrix for the place of inner dependency in supermatrix, it should be first normalized and then transposed. For normalization, the row sums are calculated as given in Eq. 5.

$$\boldsymbol{T}_E = \begin{bmatrix} t_{11}^E \cdots t_{1j}^E \cdots t_{1n}^E \\ \vdots \\ t_{i1}^E \cdots t_{ij}^E \cdots t_{in}^E \\ \vdots \\ t_{n1}^E \cdots t_{nj}^E \cdots t_{nm}^E \end{bmatrix} \begin{array}{l} \rightarrow d_1 = \sum_{j=1}^{n} t_{1j}^E \\ \\ \rightarrow d_i = \sum_{j=1}^{n} t_{ij}^E \\ \\ \rightarrow d_n = \sum_{j=1}^{n} t_{nj}^E \end{array} \tag{5}$$

where d_i represents the row sum value of the ith row. Each entry of the total relation matrix $\boldsymbol{T}_E$ is divided by the corresponding row sums as given in Eq. 6.

$$\boldsymbol{T}_E^{\alpha}=\begin{bmatrix} t_{11}^E/d_1 & \cdots & t_{1j}^E/d_1 & \cdots & t_{1n}^E/d_1\\ \vdots & & \vdots & & \vdots\\ t_{i1}^E/d_i & \cdots & t_{ij}^E/d_i & \cdots & t_{in}^E/d_i\\ \vdots & & \vdots & & \vdots\\ t_{n1}^E/d_n & \cdots & t_{nj}^E/d_n & \cdots & t_{nn}^E/d_n \end{bmatrix} = \begin{bmatrix} t_{11}^{\alpha E} & \cdots & t_{1j}^{\alpha E} & \cdots & t_{1n}^{\alpha E}\\ \vdots & & \vdots & & \vdots\\ t_{i1}^{\alpha E} & \cdots & t_{ij}^{\alpha E} & \cdots & t_{in}^{\alpha E}\\ \vdots & & \vdots & & \vdots\\ t_{n1}^{\alpha E} & \cdots & t_{nj}^{\alpha E} & \cdots & t_{nn}^{\alpha E} \end{bmatrix} \tag{6}$$

where $\boldsymbol{T}_E^{\alpha}$ represents the normalized total relation matrix for inner dependency. Finally transpose of the $\boldsymbol{T}_E^{\alpha}$ is obtained as seen in Eq. 7.

$$(\boldsymbol{T}_E^{\alpha})'=\begin{bmatrix} t_{11}^{\alpha E} & \cdots & t_{i1}^{\alpha E} & \cdots & t_{n1}^{\alpha E}\\ \vdots & & \vdots & & \vdots\\ t_{1j}^{\alpha E} & \cdots & t_{ij}^{\alpha E} & \cdots & t_{nj}^{\alpha E}\\ \vdots & & \vdots & & \vdots\\ t_{1n}^{\alpha E} & \cdots & t_{in}^{\alpha E} & \cdots & t_{nn}^{\alpha E} \end{bmatrix} \tag{7}$$

Once $(\boldsymbol{T}_E^{\alpha})'$ is obtained, it can be put into the appropriate places in supermatrix.

Suppose that the total relation matrix for inner dependency for example 2 is given by Eq. 8.

$$\boldsymbol{T}_E=\begin{bmatrix} 0.835 & 0.267 & 0.498\\ 0.708 & 0.567 & 0.825\\ 0.614 & 0.9 & 1.086 \end{bmatrix} \tag{8}$$

The row sums are calculated as given in Eq. 9.

$$T_E=\begin{bmatrix} 0.8350.2670.498\\ 0.7080.5670.825\\ 0.6140.91.086 \end{bmatrix} \begin{matrix} \to d_1=1.6\\ \to d_2=2.1\\ \to d_3=2.6 \end{matrix} \tag{9}$$

Then the normalization is applied by calculating Eq. 6. The normalized total relation matrix for inner dependency is shown in Eq. 10.

$$\boldsymbol{T}_E^{\alpha}=\begin{bmatrix} 0.835/1.6 & 0.267/1.6 & 0.498/1.6\\ 0.708/2.1 & 0.567/2.1 & 0.825/2.1\\ 0.614/2.6 & 0.900/2.6 & 1.086/2.6 \end{bmatrix} = \begin{bmatrix} 0.522 & 0.167 & 0.311\\ 0.337 & 0.27 & 0.393\\ 0.236 & 0.346 & 0.418 \end{bmatrix} \tag{10}$$

Finally transpose of the matrix $\boldsymbol{T}_E^{\alpha}$ is calculated as given in Eq. 11.

$$(\boldsymbol{T}_E^{\alpha})'=\begin{bmatrix} 0.522 & 0.337 & 0.236\\ 0.167 & 0.270 & 0.346\\ 0.311 & 0.393 & 0.418 \end{bmatrix} \tag{11}$$

The matrix $(\boldsymbol{T}_E^{\alpha})'$ is positioned into appropriate places in supermatrix as highlighted in Eq. 12.

3.2.1. Related review

Büyüközkan and Çifçi (2012) proposed a novel approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. The inner dependencies in the problem structure was handled by fuzzy DEMATEL method. The total relationship matrix was derived from DEMATEL method, and it was put into the appropriate columns in unweighted supermatrix. The rest of the supermatrix was filled by the resulting weights of fuzzy pairwise comparison matrices of fuzzy ANP method.

Büyüközkan and Öztürkcan (2010) proposed an integrated approach based on ANP and DEMATEL methods to help companies determine and prioritize critical Six Sigma projects. DEMATEL method was applied to analyze the relationships among strategies, factors and sub-factors. Inner dependencies were modeled by DEMATEL method and the total relation matrices were put into the appropriate columns in unweighted supermatrix. After weighted supermatrix had been obtained, the supermatrix was increased to sufficient large power until convergence occurs. Finally, the best project was selected.

Wu (2008) combined ANP and DEMATEL methods for choosing knowledge management strategies. Instead of making traditional pairwise comparisons for inner dependencies in unweighted supermatrix, inner dependency matrix was obtained from the DEMATEL method. A case study for evaluating and selecting a new knowledge management strategy in Taiwanese company was provided.

Shen, Lin, and Tzeng (2011) proposed a hybrid MADM method integrating DEMATEL and ANP to construct a technology selection model. DEMATEL method was used to capture inner dependencies among dimensions and criteria. Inner dependencies among criteria were analyzed by DEMATEL method, and the resulting total relation matrix was put into the appropriate parts of the unweighted supermatrix. On the other hand, the traditional pairwise comparisons of ANP was conducted for outer dependencies based on the existence of relationships among dimensions. In this study, DEMATEL method was served as a tool for both constructing NRM and obtaining inner dependencies.

Tseng (2011) proposed a framework based on fuzzy set theory, DEMATEL and ANP for measuring environmental knowledge management capability. The inner dependency matrix was obtained from DEMATEL method. After normalization of the unweighted supermatrix, it was raised to sufficient powers to acquire steady-state matrix. Finally, success factors were determined and managerial implications were given.

Tseng (2009) combined DEMATEL and ANP methods for effective solution of municipal solid waste management in Metro Manila region in Philippines. DEMATEL method was used to capture the cause and effect relationships among criteria. The decision criteria were structured as a single-cluster. The causal relationships among single-clustered criteria were handled via DEMATEL method. The unweighted supermatrix was formed based on inner dependency matrix, which was obtained from DEMATEL.

Bakeshlou, Khamseh, Asl, Sadeghi, and Abbaszadeh (2014) studied green supplier selection problem by using multi-objective fuzzy linear programming, DEMATEL, and ANP. The inner dependency matrix obtained from DEMATEL method was used to form unweighted supermatrix in ANP. Then, multi-objective fuzzy linear programming

$$\boldsymbol{W}=\begin{array}{c} \\ c_1\\ c_2\\ c_3\\ c_4\\ c_5\\ c_6\\ c_7\\ c_8\\ c_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \end{array}\\ \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 & 0.58 & 0.28\\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.60 & 0.22 & 0.46\\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 & 0.20 & 0.26\\ 0.60 & 0.51 & 0.31 & 0.522 & 0.337 & 0.236 & 0.44 & 0.35 & 0.44\\ 0.20 & 0.37 & 0.41 & 0.167 & 0.270 & 0.346 & 0.15 & 0.30 & 0.36\\ 0.20 & 0.12 & 0.28 & 0.311 & 0.393 & 0.418 & 0.41 & 0.35 & 0.20\\ 0.13 & 0.27 & 0.41 & 0.25 & 0.32 & 0.20 & 0.00 & 0.00 & 0.00\\ 0.21 & 0.63 & 0.42 & 0.23 & 0.46 & 0.30 & 0.00 & 0.00 & 0.00\\ 0.66 & 0.10 & 0.17 & 0.52 & 0.22 & 0.50 & 0.00 & 0.00 & 0.00 \end{bmatrix} \end{array} \tag{12}$$

was used to determine optimal order allocations to selected suppliers.

Tadić, Zečević, and Krstić (2014) combined fuzzy DEMATEL, fuzzy ANP, and fuzzy VIKOR methods for city logistics concept selection. Fuzzy DEMATEL method was used to capture the inner dependencies within factor groups. The outer dependencies were calculated based on fuzzy pairwise comparison matrices. Then, the inner and outer dependencies were entered into the appropriate columns of the supermatrix. Finally, supermatrix was raised to limiting powers to obtain final weights. Fuzzy VIKOR was used to select the best city logistics concept.

3.3. Cluster-weighted ANP

Generalizing the hierarchical decomposition of AHP, the ANP method makes use of clusters, and criteria are placed within the clusters. The relationship between criteria is determined by pairwise comparisons. Then the corresponding weights are placed in the appropriate columns of the supermatrix. While relationships between elements are quantified in the ANP, those between clusters are generally not considered. In most of the studies, the relationships between clusters are assumed to be the same.

In fact, each cluster has not the same priority for the decision maker. The importance of the criterion is not only affected by the influence emitted from other elements but it also depends on the cluster that the criterion belongs to. Accordingly, the cluster-weighted ANP approach applies DEMATEL method to quantify the influence degrees among clusters, and use these values to weight the supermatrix. Note that inner and outer dependencies are still handled via traditional pairwise comparisons of ANP. The supermatrix takes the form as given in Eq. 13. Each block in the supermatrix is weighted by the appropriate cluster weights obtained by using DEMATEL method.

$$\boldsymbol{W} = \begin{array}{c c} & \begin{array}{ccc} \underset{e_{11}\cdots e_{1m_1}\cdots}{D_1} & \underset{e_{j1}\cdots e_{jm_j}\cdots}{D_j} & \underset{e_{n1}\cdots e_{nm_n}}{D_n} \end{array} \\ \begin{array}{c} D_1 \; e_{11}, e_{12}, \ldots, e_{1m_1} \\ \vdots \\ D_i \; e_{i1}, e_{i2}, \ldots, e_{im_i} \\ \vdots \\ D_n \; e_{n1}, e_{n2}, \ldots, e_{nm_n} \end{array} & \begin{bmatrix} W_{11} & \cdots & W_{1j} & \cdots & W_{1n} \\ \vdots & & \vdots & & \vdots \\ W_{i1} & \cdots & W_{ij} & \cdots & W_{in} \\ \vdots & & \vdots & & \vdots \\ W_{n1} & \cdots & W_{nj} & \cdots & W_{nn} \end{bmatrix} \end{array} \tag{13}$$

Procedural steps of the cluster weighted ANP method can be summarized as follows (Yang, Shieh, Leu, & Tzeng, 2008); at the beginning, direct relation matrix for clusters is constructed. Applying DEMATEL method (Eqs. B.1–B.4, given in Appendix B), total relation matrix is formed. Then a threshold value is set to ignore the relationships that have minor impacts. When the threshold is applied, influences that are smaller than the threshold are set to zero in total relation matrix. Accordingly, total relation matrix for clusters $\boldsymbol{T}_D$ is formed. Then, row-sums of the total relation matrix are calculated. For instance, summation of the ith row of the total relation matrix is denoted by d_i and the calculation is shown in Eq. 14.

$$\boldsymbol{T}_D = \begin{bmatrix} t_{11}^D & \cdots & t_{1j}^D & \cdots & t_{1n}^D \\ \vdots & & \vdots & & \vdots \\ t_{i1}^D & \cdots & t_{ij}^D & \cdots & t_{in}^D \\ \vdots & & \vdots & & \vdots \\ t_{n1}^D & \cdots & t_{nj}^D & \cdots & t_{nn}^D \end{bmatrix} \longrightarrow d_i = \sum_{j=1}^{n} t_{ij}^D \tag{14}$$

where t_{ij}^D represents the degree of influence that the cluster i exerts on the cluster j. Then, row sums are used to calculate the normalized total relation matrix for clusters, which is denoted by $\boldsymbol{T}_D^\alpha$. Each element is divided by the corresponding row sums in the normalization process, which is given in Eq. 15.

$$\boldsymbol{T}_D^\alpha = \begin{bmatrix} t_{11}^D/d_1 & \cdots & t_{1j}^D/d_1 & \cdots & t_{1n}^D/d_1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^D/d_i & \cdots & t_{ij}^D/d_i & \cdots & t_{in}^D/d_i \\ \vdots & & \vdots & & \vdots \\ t_{n1}^D/d_n & \cdots & t_{nj}^D/d_n & \cdots & t_{nn}^D/d_n \end{bmatrix}$$
$$\boldsymbol{T}_D^\alpha = \begin{bmatrix} t_{11}^{\alpha D} & \cdots & t_{1j}^{\alpha D} & \cdots & t_{1n}^{\alpha D} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha D} & \cdots & t_{ij}^{\alpha D} & \cdots & t_{in}^{\alpha D} \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{\alpha D} & \cdots & t_{nj}^{\alpha D} & \cdots & t_{nn}^{\alpha D} \end{bmatrix} \tag{15}$$

where $t_{ij}^{\alpha D} = t_{ij}^D/d_i$. Finally, the normalized total relation matrix is used to weight the unweighted supermatrix. The weighted supermatrix $\boldsymbol{W}_w$is calculated as given in Eq. 16:

$$\boldsymbol{W}_w = \begin{bmatrix} t_{11}^{\alpha D} \times \boldsymbol{W}_{11} & t_{21}^{\alpha D} \times \boldsymbol{W}_{12} & \cdots & \cdots & t_{n1}^{\alpha D} \times \boldsymbol{W}_{1n} \\ t_{12}^{\alpha D} \times \boldsymbol{W}_{21} & t_{22}^{\alpha D} \times \boldsymbol{W}_{22} & \vdots & & \vdots \\ \vdots & \vdots & \cdots & \cdots & t_{ni}^{\alpha D} \times \boldsymbol{W}_{in} \\ \vdots & \vdots & \vdots & & \vdots \\ t_{1n}^{\alpha D} \times \boldsymbol{W}_{n1} & t_{2n}^{\alpha D} \times \boldsymbol{W}_{n2} & \cdots & \cdots & t_{nn}^{\alpha D} \times \boldsymbol{W}_{nn} \end{bmatrix} \tag{16}$$

Once the weighted supermatrix is obtained, the limiting supermatrix can be calculated to reach overall priorities.

Example 3. In the previous sections, the total relation matrix for clusters is only used for constructing NRM. The total relation matrix for clusters can also be used for weighting the supermatrix. In order to normalize the total relation matrix, row sums are calculated as given in Eq. 17.

$$\boldsymbol{T}_D = \begin{bmatrix} 00.960.55 \\ 00.520.80 \\ 0.200.600 \end{bmatrix} \begin{array}{l} \to d_1 = 1.51 \\ \to d_2 = 1.32 \\ \to d_3 = 0.80 \end{array} \tag{17}$$

Then, each element is divided by the row sums as seen in Eq. 18.

$$\boldsymbol{T}_D^\alpha = \begin{bmatrix} 0/1.51 & 0.96/1.51 & 0.55/1.51 \\ 0/1.32 & 0.52/1.32 & 0.80/1.32 \\ 0.20/0.80 & 0.60/0.80 & 0/0.80 \end{bmatrix} = \begin{bmatrix} 0 & 0.64 & 0.36 \\ 0 & 0.39 & 0.61 \\ 0.25 & 0.75 & 0 \end{bmatrix} \tag{18}$$

Using the cluster weights, the unweighted supermatrix is weighted as shown in Eq. 19.

$$\boldsymbol{W}_w = \begin{array}{c c} & \begin{array}{ccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \end{array} \\ \begin{array}{c} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \end{array} & \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 \times 0.25 & 0.58 \times 0.25 & 0.28 \times 0.25 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.60 \times 0.25 & 0.22 \times 0.25 & 0.46 \times 0.25 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.20 \times 0.25 & 0.20 \times 0.25 & 0.26 \times 0.25 \\ 0.60 \times 0.64 & 0.51 \times 0.64 & 0.31 \times 0.64 & 0.50 \times 0.39 & 0.33 \times 0.39 & 0.16 \times 0.39 & 0.44 \times 0.75 & 0.35 \times 0.75 & 0.44 \times 0.75 \\ 0.20 \times 0.64 & 0.37 \times 0.64 & 0.41 \times 0.64 & 0.32 \times 0.39 & 0.40 \times 0.39 & 0.62 \times 0.39 & 0.15 \times 0.75 & 0.30 \times 0.75 & 0.36 \times 0.75 \\ 0.20 \times 0.64 & 0.12 \times 0.64 & 0.28 \times 0.64 & 0.18 \times 0.39 & 0.27 \times 0.39 & 0.22 \times 0.39 & 0.41 \times 0.75 & 0.35 \times 0.75 & 0.20 \times 0.75 \\ 0.13 \times 0.36 & 0.27 \times 0.36 & 0.41 \times 0.36 & 0.25 \times 0.61 & 0.32 \times 0.61 & 0.20 \times 0.61 & 0.00 & 0.00 & 0.00 \\ 0.21 \times 0.36 & 0.63 \times 0.36 & 0.42 \times 0.36 & 0.23 \times 0.61 & 0.46 \times 0.61 & 0.30 \times 0.61 & 0.00 & 0.00 & 0.00 \\ 0.66 \times 0.36 & 0.10 \times 0.36 & 0.17 \times 0.36 & 0.52 \times 0.61 & 0.22 \times 0.61 & 0.50 \times 0.61 & 0.00 & 0.00 & 0.00 \end{bmatrix} \end{array} \tag{19}$$

Finally, the weighted supermatrix is given in Eq. 20.

$$\boldsymbol{W}_w = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \end{array} \\ \begin{bmatrix} 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.050 & 0.145 & 0.070 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.150 & 0.055 & 0.115 \\ 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.050 & 0.050 & 0.065 \\ 0.384 & 0.326 & 0.198 & 0.195 & 0.129 & 0.062 & 0.330 & 0.262 & 0.330 \\ 0.128 & 0.237 & 0.262 & 0.125 & 0.156 & 0.242 & 0.112 & 0.225 & 0.270 \\ 0.128 & 0.077 & 0.179 & 0.070 & 0.105 & 0.086 & 0.308 & 0.263 & 0.150 \\ 0.047 & 0.097 & 0.148 & 0.153 & 0.195 & 0.122 & 0.000 & 0.000 & 0.000 \\ 0.076 & 0.227 & 0.151 & 0.140 & 0.281 & 0.183 & 0.000 & 0.000 & 0.000 \\ 0.238 & 0.036 & 0.061 & 0.317 & 0.134 & 0.305 & 0.000 & 0.000 & 0.000 \end{bmatrix} \end{array} \tag{20}$$

The weighted supermatrix is then raised to powers to calculate the final priorities.

3.3.1. Related review

Yang, Shieh, and Tzeng (2013) proposed a MADM method, combining the modified VIKOR, DEMATEL and ANP for information security risk control assessment. DEMATEL method was employed to extract NRM of the problem. Then pairwise comparisons were conducted to form unweighted supermatrix. Additionally, unlike the common assumption that each cluster has the same weight in ANP, the DEMATEL method was applied to take different importance degrees of clusters into account. Unweighted supermatrix was multiplied by the importance degrees of clusters, which were captured by DEMATEL method, and weighted supermatrix was calculated.

Yang and Tzeng (2011) proposed an integrated MADM method by combining DEMATEL and ANP. Since using average method to obtain the weighted supermatrix was considered unrealistic under the assumption of non-equal cluster weights, the DEMATEL method was served as the basis for normalization of supermatrix process in ANP. A case study was proposed for selecting the appropriate vendor in a purchase project.

Chen and Chen (2011) explored the critical creativity criteria by DEMATEL and ANP methods. DEMATEL method was adopted to construct NRM. Based on the NRM derived by DEMATEL, pairwise comparisons were made and unweighted supermatrix was formed. The unweighted supermatrix was then weighted by the total influence matrix of dimensions. Finally, weighted supermatrix was raised to large powers, and the critical criteria were indicated.

Chen, Lien, and Tzeng (2010) used hybrid MADM model based on DEMATEL and ANP for evaluation of environmental watershed plans. DEMATEL method was used to construct the NRM. Then, unweighted supermatrix was formed involving Saaty's 9-point scale based on the NRM. Then, unweighted supermatrix was weighted by DEMATEL method. Finally, limiting powers of the weighted supermatrix were calculated.

Wu et al. (2011) evaluated the intellectual capital of Taiwan's higher education system by using DEMATEL and ANP. DEMATEL method was used to develop NRM. Based on the NRM, ANP method was exploited by using Saaty's 1–9 measurement scale. After unweighted supermatrix was formed, weighted supermatrix was obtained by multiplying unweighted supermatrix with the influence matrix of dimensions acquired from DEMATEL. Finally, the most important criteria were determined and managerial insights were given.

Wang (2012) evaluated interactive trade policies using DEMATEL and ANP. The DEMATEL method was used to depict the NRM of the problem. Then, the traditional ANP steps were performed to obtain unweighted supermatrix. Then, the unweighted supermatrix was multiplied by the influences of clusters acquired from the DEMATEL method. Finally, the steady state priorities were obtained by raising weighted supermatrix to sufficiently large powers.

Zhou, Bai, and Sun (2014) analyzed causal relationships between human factors in high-risk hydropower construction projects using DEMATEL and ANP methods. Different degrees of effects among clusters were taken into account in obtaining the weighted supermatrix. Suggestions for safety management in the high-risk work systems were provided.

Chyu and Fang (2014) applied a hybrid MADM method to new product development selection problem. DEMATEL method was used to modulate the criteria weights obtained from traditional pairwise comparisons. Unweighted supermatrix was weighted by unequal cluster degrees obtained from DEMATEL method. Finally, the most suitable new color calibration device alternatives were ranked by TOPSIS and GRA methods.

Baykasoglu and Durmusoglu (2014) proposed a DEMATEL and ANP based hybrid approach for private primary school selection problem. Unlike the traditional DEMATEL method, different threshold functions such as linear and hyperbolic tangent functions were utilized to calculate the total relation matrix. DEMATEL results were used to normalize the unweighted supermatrix of ANP.

Hu, Chiu, Yen, and Cheng (2015) proposed an integrated approach by using DEMATEL and ANP methods for supplier quality performance assessment. The traditional pairwise comparisons were conducted and the supermatrix was formed. DEMATEL method was used to adjust the importance of the evaluation criteria by considering causal relationships. A case study in a computer manufacturer in Taiwan was provided.

3.4. DANP

Different hybrid methods have been overviewed so far. The DANP method combines the advantages of other hybrid techniques that are mentioned earlier. The DANP method applied by Chen et al. (2011) modifies the original ANP so as to reduce its inherent difficulties.

As already mentioned in the previous sections, the survey questionnaire of the ANP can be rather difficult for decision makers to interpret and provide accurate information. The DANP method combines four different approaches as shown in Fig. 8.

Similar to other hybrid DEMATEL-ANP combinations, DANP method utilizes total relation matrix for clusters to establish NRM of the decision model. Based on the NRM, the influential relationships are obtained. In traditional ANP method, the unweighted supermatrix is formed according to pairwise comparisons, and ultimately the criteria weights which correspond to eigenvalues are placed into the appropriate columns of the supermatrix. In order to remedy difficulties of the pairwise comparison questions and the cognitive burden that decision makers bear, DANP method modifies the pairwise comparison questions. Notwithstanding, DANP forms a comprehensive unweighted supermatrix by building direct- influence matrix where pairwise comparisons are not only conducted within clusters but for the whole system in compliance with the problem structure. In this respect, DANP method generalizes the modeling of inner dependency partitions by DEMATEL method. When the unweighted supermatrix is constructed, the total relation matrices among clusters are used to weight the appropriate portions of the supermatrix in order to get the weighted supermatrix. Hence, DANP method is also a general form of cluster-weighted ANP. Finally, DANP method avoids the tangled questions of 9-scale pairwise comparison surveys and puts the total relation matrix formation forward in lieu of it.

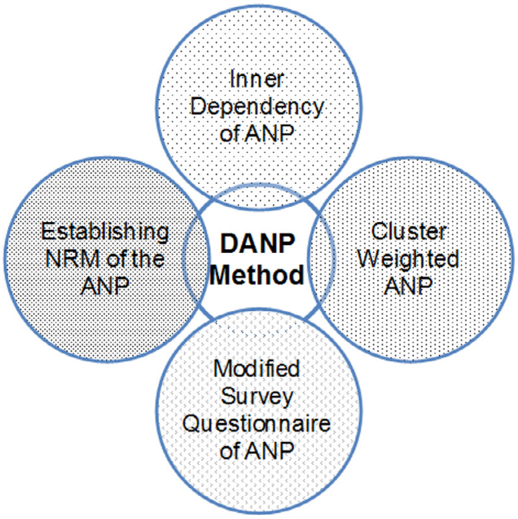

Fig. 8. Components of DANP Method.

The basic steps of the DANP method can be given as follows (Chen et al., 2011; Liu et al., 2012); in the first step of the evaluation, NRM of the ANP is captured by using DEMATEL as mentioned in Section 3.1. Then, an unweighted supermatrix for the whole system is constructed. The total relation matrices for clusters and criteria are calculated. The total relation matrix for all the criteria is denoted by $\boldsymbol{T}_C$ as given in Eq. 21.

$$\boldsymbol{T}_C = \begin{array}{c} \\ D_1 \\ \vdots \\ D_i \\ \vdots \\ D_n \end{array} \begin{array}{c} \begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{T}_C^{11} & \cdots & \boldsymbol{T}_C^{1j} & \cdots & \boldsymbol{T}_C^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{i1} & \cdots & \boldsymbol{T}_C^{ij} & \cdots & \boldsymbol{T}_C^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{n1} & \cdots & \boldsymbol{T}_C^{nj} & \cdots & \boldsymbol{T}_C^{nn} \end{bmatrix} \end{array} \tag{21}$$

Then, normalized total relation matrix for criteria, which is denoted by $\boldsymbol{T}_C^{\alpha}$ is calculated. Row sum of the each sub-matrix of the $\boldsymbol{T}_C$ is calculated to conduct normalization. For instance, row sum values for the sub-matrix $\boldsymbol{T}_C^{12}$ are calculated as given in Eq. 22.

$$\boldsymbol{T}_c^{12} = \begin{array}{c} \\ c_{11} \\ \vdots \\ c_{1i} \\ \vdots \\ c_{1m_1} \end{array} \begin{array}{c} \begin{array}{ccccc} c_{21} & \cdots & c_{2j} & \cdots & c_{2m_2} \end{array} \\ \begin{bmatrix} t_{11}^{12} & \cdots & t_{1j}^{12} & \cdots & t_{1m_2}^{12} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{12} & \cdots & t_{ij}^{12} & \cdots & t_{im_2}^{12} \\ \vdots & & \vdots & & \vdots \\ t_{m_1 1}^{12} & \cdots & t_{m_1 j}^{12} & \cdots & t_{m_1 m_2}^{12} \end{bmatrix} \end{array} \begin{array}{l} \\ \to d_1^{12} = \sum_{j=1}^{m_2} t_{1j}^{12} \\ \\ \to d_i^{12} = \sum_{j=1}^{m_2} t_{ij}^{12} \\ \\ \to d_{m_1}^{12} = \sum_{j=1}^{m_2} t_{m_1 j}^{12} \end{array} \tag{22}$$

where d_i^{12} represents ith row sum of the total relation matrix $\boldsymbol{T}_C^{12}$, and $d_i^{12} = \sum_{j=1}^{m_2} t_{ij}^{12}$, $i = 1, 2, \ldots, m_1$.

Then, each row is divided by the corresponding row sum value for normalization. The normalization procedure for $\boldsymbol{T}_C^{12}$ is shown in Eq. 23.

$$\boldsymbol{T}_C^{\alpha 12} = \begin{bmatrix} t_{11}^{12}/d_1^{12} & \cdots & t_{1j}^{12}/d_1^{12} & \cdots & t_{1m_2}^{12}/d_1^{12} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{i1}^{12}/d_i^{12} & \cdots & t_{ij}^{12}/d_i^{12} & \cdots & t_{im_2}^{12}/d_i^{12} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ t_{m_1 1}^{12}/d_{m_1}^{12} & \cdots & t_{m_1 j}^{12}/d_{m_1}^{12} & \cdots & t_{m_1 m_2}^{12}/d_{m_1}^{12} \end{bmatrix}$$

$$= \begin{bmatrix} t_{11}^{\alpha 12} & \cdots & t_{1j}^{\alpha 12} & \cdots & t_{1m_2}^{\alpha 12} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha 12} & \cdots & t_{ij}^{\alpha 12} & \cdots & t_{im_2}^{\alpha 12} \\ \vdots & & \vdots & & \vdots \\ t_{m_1 1}^{\alpha 12} & \cdots & t_{m_1 j}^{\alpha 12} & \cdots & t_{m_1 m_2}^{\alpha 12} \end{bmatrix} \tag{23}$$

The normalized total relation matrix for criteria takes the form as given in Eq. 24.

$$\boldsymbol{T}_C^{\alpha} = \begin{array}{c} \\ D_1 \\ \vdots \\ D_i \\ \vdots \\ D_n \end{array} \begin{array}{c} \begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{T}_C^{\alpha 11} & \cdots & \boldsymbol{T}_C^{\alpha 1j} & \cdots & \boldsymbol{T}_C^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{\alpha i1} & \cdots & \boldsymbol{T}_C^{\alpha ij} & \cdots & \boldsymbol{T}_C^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{\alpha n1} & \cdots & \boldsymbol{T}_C^{\alpha nj} & \cdots & \boldsymbol{T}_C^{\alpha nn} \end{bmatrix} \end{array} \tag{24}$$

When the normalized total relation matrix is obtained, the next step is to form an unweighted supermatrix. The unweighted supermatrix is formed by taking the transposition of the each block in the normalized total relation matrix as seen in Eq. 25.

$$\boldsymbol{W} = \left(\boldsymbol{T}_C^{\alpha}\right)' = \begin{array}{c} \\ C_1 \\ \vdots \\ C_i \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & & C_k & & C_n \\ e_{11}\cdots e_{1m_1} & \cdots & e_{j1}\cdots e_{jm_j} & \cdots & e_{n1}\cdots e_{nm_n} \end{array} \\ \begin{bmatrix} \boldsymbol{W}_{11} & \cdots & \boldsymbol{W}_{1j} & \cdots & \boldsymbol{W}_{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}_{i1} & \cdots & \boldsymbol{W}_{ij} & \cdots & \boldsymbol{W}_{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}_{n1} & \cdots & \boldsymbol{W}_{nj} & \cdots & \boldsymbol{W}_{nn} \end{bmatrix} \end{array} \tag{25}$$

where $\boldsymbol{W}_{ij} = (\boldsymbol{T}_C^{\alpha ji})'$, $i = 1, 2, \ldots n$, $j = 1, 2, \ldots n$.

For instance, the elements of $\boldsymbol{W}_{21}$ is given by Eq. 26.

$$\boldsymbol{W}_{21} = \left(\boldsymbol{T}_C^{12}\right)' = \begin{array}{c} \\ c_{11} \\ \vdots \\ c_{2j} \\ \vdots \\ c_{2m_2} \end{array} \begin{array}{c} \begin{array}{ccccc} c_{11} & \cdots & c_{1j} & \cdots & c_{1m_1} \end{array} \\ \begin{bmatrix} t_{11}^{\alpha 12} & \cdots & t_{i1}^{\alpha 12} & \cdots & t_{m_1 1}^{\alpha 12} \\ \vdots & & \vdots & & \vdots \\ t_{1j}^{\alpha 12} & \cdots & t_{ij}^{\alpha 12} & \cdots & t_{m_1 j}^{\alpha 12} \\ \vdots & & \vdots & & \vdots \\ t_{1m_2}^{\alpha 12} & \cdots & t_{im_2}^{\alpha 12} & \cdots & t_{m_1 m_2}^{\alpha 12} \end{bmatrix} \end{array} \tag{26}$$

When the unweighted supermatrix is constructed, the total relation matrix for clusters, which is denoted by $\boldsymbol{T}_D$, is used to weight the unweighted supermatrix. Because all the required steps for obtaining weighted supermatrix are given in Section 3.3, they are not repeated here. Eqs. 14–16 are used to obtain the weighted supermatrix. Then, the weighted supermatrix is raised to limiting powers to obtain final priorities.

Example 4. Let us solve the decision problem presented in previous sections by using DANP method. First, the NRM of the problem is captured by using the DEMATEL method. Note that the NRM is already constructed in example 1. The next step is to construct the unweighted supermatrix based upon the NRM. DANP method employs DEMATEL method for construction of the unweighted supermatrix. For that aim, the criteria in the whole system are compared, and the total relation matrix for criteria is constructed as seen in Fig. 9.

The next step is to calculate the normalized total relation matrices. Each element is divided by the corresponding row sums for normalization. For instance, $\boldsymbol{T}_C^{31}$ is normalized as given in Eq. 27–28.

$$\boldsymbol{T}_C^{31} = \begin{bmatrix} 0.43 & 0.428 & 1.442 \\ 2.041 & 0.55 & 1.609 \\ 0.389 & 0.353 & 0.458 \end{bmatrix} \begin{array}{l} \to d_1 = 2.3 \\ \to d_2 = 4.2 \\ \to d_3 = 1.2 \end{array} \tag{27}$$

		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	
	c_1	0.000	0.000	0.000	0.050	0.014	0.036	0.027	0.027	0.066	
T_C^{11}	c_2	0.000	0.000	0.000	0.089	0.073	0.038	0.558	0.076	1.366	T_C^{13}
	c_3	0.000	0.000	0.000	0.059	0.126	0.065	0.369	0.223	0.558	
	c_4	0.000	0.000	0.000	0.835	0.267	0.498	0.755	0.845	1.600	
$T_C = T_C^{21}$	c_5	0.000	0.000	0.000	0.708	0.567	0.825	0.706	0.534	0.360	T_C^{23}
	c_6	0.000	0.000	0.000	0.614	0.900	1.086	0.316	0.570	0.514	
	c_7	0.430	0.428	1.442	1.469	0.571	1.360	0.000	0.000	0.000	
T_C^{31}	c_8	2.041	0.550	1.609	0.310	0.697	0.793	0.000	0.000	0.000	T_C^{33}
	c_9	0.389	0.353	0.458	0.424	0.445	0.531	0.000	0.000	0.000	

Fig. 9. The total relation matrix of Example 4.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	
	c_1	0.000	0.000	0.000	0.503	0.143	0.354	0.227	0.226	0.547	
$T_C^{\alpha 11}$	c_2	0.000	0.000	0.000	0.447	0.365	0.188	0.279	0.038	0.683	$T_C^{\alpha 13}$
	c_3	0.000	0.000	0.000	0.237	0.505	0.258	0.321	0.194	0.485	
	c_4	0.000	0.000	0.000	0.522	0.167	0.311	0.236	0.264	0.5	
$T_C^{\alpha} = T_C^{\alpha 21}$	c_5	0.000	0.000	0.000	0.337	0.27	0.393	0.441	0.334	0.225	$T_C^{\alpha 23}$
	c_6	0.000	0.000	0.000	0.236	0.346	0.418	0.226	0.407	0.367	
	c_7	0.187	0.186	0.627	0.432	0.168	0.4	0.000	0.000	0.000	
$T_C^{\alpha 31}$	c_8	0.486	0.131	0.383	0.172	0.387	0.441	0.000	0.000	0.000	$T_C^{\alpha 33}$
	c_9	0.324	0.294	0.382	0.303	0.318	0.379	0.000	0.000	0.000	

Fig. 10. The normalized total relation matrix of Example 4.

$$T_C^{\alpha 31} = \begin{bmatrix} 0.43/2.3 & 0.428/2.3 & 1.442/2.3 \\ 2.041/4.2 & 0.55/4.2 & 1.609/4.2 \\ 0.389/1.2 & 0.353/1.2 & 0.458/1.2 \end{bmatrix} = \begin{bmatrix} 0.187 & 0.186 & 0.627 \\ 0.486 & 0.131 & 0.383 \\ 0.324 & 0.294 & 0.382 \end{bmatrix} \quad (28)$$

The normalized total relation matrix of Example 4 is given in Fig. 10.

Then, the transpose of the each normalized total relation matrix is calculated. For instance, transpose of the normalized total relation matrix $T_C^{\alpha 31}$ is calculated as given in Eq. 29:

$$\left(T_C^{\alpha 31}\right)' = \begin{bmatrix} 0.187 & 0.486 & 0.324 \\ 0.186 & 0.131 & 0.294 \\ 0.627 & 0.383 & 0.382 \end{bmatrix} \quad (29)$$

Similar calculations are made for all of the normalized total relation matrices. Then, the transpose of the normalized total relation matrices are placed into appropriate columns of the supermatrix to form unweighted supermatrix as given in Fig. 11.

Then, the cluster weights given in Eq. 18 are used to calculate the weighted supermatrix as elaborated in Section 3.3. The weighted supermatrix is calculated as given in Fig. 12.

When the weighted supermatrix is raised to large powers, the steady-state criteria weights can be obtained.

3.4.1. Related review

Chen et al. (2011) introduced a hybrid MADM model for performance evaluation of hot spring hotels based on balanced scorecards and DANP. First, the DEMATEL method was used to draw a causal relationship map of criteria. Then, total influence matrix for fifteen criteria and four perspectives were generated by using DEMATEL method. Total influence matrix for criteria was place into the appropriate columns of supermatrix, thereby unweighted supermatrix was formed. On the other hand, total influence matrix for perspectives was utilized to weight the unweighted supermatrix. In the last step, overall priorities were calculated by using limiting process of weighted supermatrix.

Lee, Huang, Chang, and Cheng (2011) studied the interactive relationships among equity investment factors by using DANP. A hybrid method was developed by extending the study of Yang et al. (2008).

		c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	
	c_1	0.00	0.00	0.00	0.00	0.00	0.00	0.187	0.486	0.324	
W_{11}	c_2	0.00	0.00	0.00	0.00	0.00	0.00	0.186	0.131	0.294	$W_{13} = \left(T_C^{\alpha 31}\right)'$
	c_3	0.00	0.00	0.00	0.00	0.00	0.00	0.627	0.383	0.382	
	c_4	0.503	0.447	0.237	0.522	0.337	0.236	0.43	0.17	0.30	
$W = W_{21}$	c_5	0.143	0.365	0.505	0.167	0.270	0.346	0.17	0.39	0.32	
	c_6	0.354	0.188	0.258	0.311	0.393	0.418	0.40	0.44	0.38	
	c_7	0.227	0.279	0.321	0.236	0.441	0.226	0.00	0.00	0.00	
W_{31}	c_8	0.226	0.038	0.194	0.264	0.334	0.407	0.00	0.00	0.00	
	c_9	0.547	0.683	0.485	0.500	0.225	0.367	0.00	0.00	0.00	

Fig. 11. The unweighted supermatrix of Example 4.

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$$
\boldsymbol{W}_w = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \\ c_7 \\ c_8 \\ c_9 \end{array}
\begin{array}{ccc|ccc|ccc}
c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 & c_8 & c_9 \\
\hline
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.047 & 0.122 & 0.081 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.047 & 0.033 & 0.074 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.157 & 0.096 & 0.096 \\
\hline
0.322 & 0.286 & 0.152 & 0.204 & 0.131 & 0.092 & 0.324 & 0.129 & 0.227 \\
0.091 & 0.234 & 0.322 & 0.065 & 0.105 & 0.135 & 0.125 & 0.290 & 0.238 \\
0.227 & 0.120 & 0.165 & 0.121 & 0.154 & 0.163 & 0.300 & 0.330 & 0.284 \\
\hline
0.082 & 0.100 & 0.116 & 0.144 & 0.269 & 0.138 & 0.000 & 0.000 & 0.000 \\
0.081 & 0.014 & 0.070 & 0.161 & 0.204 & 0.248 & 0.000 & 0.000 & 0.000 \\
0.197 & 0.246 & 0.175 & 0.305 & 0.137 & 0.224 & 0.000 & 0.000 & 0.000 \\
\hline
\end{array}
$$

Fig. 12. The weighted supermatrix of Example 4.

First, the DEMATEL method was used for clarifying the different degrees of influences among clusters. Then, total-influence matrix was constructed considering all the criteria, and it was incorporated into supermatrix. Then the unweighted supermatrix was weighted by cluster weights obtained from DEMATEL method.

Wang and Tzeng (2012) proposed a hybrid MADM model combining DANP and VIKOR for ranking brand marketing strategies. DEMATEL method was not only used for constructing the NRM, but also providing input data for supermatrix formation in ANP. First, the initial influence matrices for criteria and clusters were formed. The total-influence matrix for criteria was obtained from DEMATEL, and its transposed form was placed into the unweighted supermatrix. Then, normalized total-influence matrix for clusters was used to obtain weighted supermatrix by weighting appropriate cells of the unweighted supermatrix. Once the weighted supermatrix was formed, it was raised to a sufficiently large powers to obtain ultimate weights.

Chen and Sun (2012) applied DANP method to find the best leisure sport and important factors that enhance senior citizens' participation in recreational sports. The DEMATEL method was used to obtain total influence matrix for criteria and clusters. Then the unweighted supermatrix was established incorporating the total influence matrix for criteria. Afterwards, unweighted supermatrix was normalized by the cluster weights obtained from DEMATEL method. Finally, weighted supermatrix was raised to sufficiently large powers to obtain the best alternative and criteria weights.

Tseng (2010) proposed fuzzy network balanced scorecard approach by combining fuzzy set theory and DANP. In the supermatrix of the ANP, inner and outer dependencies were calculated based on DEMATEL method. Furhermore, weighted supermatrix was calculated by using DEMATEL results. The final weights were achieved by converged weighted supermatrix.

Liu et al. (2012) proposed a hybrid MADM method with DANP and VIKOR methods to determine the optimal improvement plan for Taiwan tourism policy. DEMATEL method was not only used to draw a NRM but also construct the unweighted supermatrix in ANP. Weights of criteria found by ANP was used within VIKOR method, and gaps to the aspired levels were discussed.

Vujanović, Momčilović, Bojović, and Papić (2012) assessed the vehicle fleet maintenance management indicators with DANP. DEMATEL method was used to construct the NRM and clarify the interdependencies between criteria and clusters. Also, the total relation matrix for criteria was constructed, which was incorporated into the supermatrix in order to build unweighted supermatrix. The unweighted supermatrix was weighted by the influences among clusters obtained by DEMATEL. Finally, the priorities of the maintenance indicators were used in maintenance management process.

Hung et al. (2012) used DANP for evaluating the online reputation management model to advance the internet marketing services. DEMATEL method was used to acquaire the NRM of the clusters and criteria. Also, the total relation matrix was used to construct the unweighted supermatrix. After weighting the supermatrix by total relation matrix of DEMATEL method, steady state weights were calculated to prioritize online reputation factors.

Hsu, Wang, and Tzeng (2012) studied vendor selection problem under environmentally conscious manufacturing and product recovery environment using DANP and VIKOR. The unweighted and weighted supermatrices were formed by using the total relation matrices of DEMATEL method. After the criteria weights were obtained, VIKOR method was employed to rank the vendors.

Chiu, Tzeng, and Li (2013) proposed a hybrid method for analyzing improvement strategies of e-store businesses. DANP method was used to clarify interdependencies, form unweighted and weighted supermatrices, and obtain final priorities without using traditional pairwise comparisons of the ANP. VIKOR method was utilized to rank the e-store strategies.

In the rest of the papers, very similar methodological steps were observed. DANP was employed to construct NRM of the criteria, the unweighted supermatrix was formed and weighted by means of DEMATEL method application results, and the limiting supermatrix was calculated to obtain final weights. The rest of the papers can be briefly summarized as follows:

Horng, Chou, Liu, and Tsai (2013) discovered the vital criteria of innovative physical dining environment design by using DANP method. Hsu and Liou (2013) evaluated outsourcing decisions for the airline industry by using DANP method. Hsu, Liou, and Chuang (2013) integrated DANP and grey relation analysis for outsourcing provider selection problem. Peng and Tzeng (2013) developed a hybrid dynamic MADM method based on DANP and fuzzy integral methods for economics and business applications. Shen and Tzeng (2015) proposed an integrated model by using dominance-based rough sets, DANP, and VIKOR methods. Liou, Chuang, and Tzeng (2014) integrated fuzzy integral and DANP methods for supplier improvement and selection problem. Chen, Huang, and Tsuei (2014) established a decision making model by using DANP and geographical information systems for solar farms site selection problem. Huang, Liou, and Chuang (2014) analyzed interdependencies and feedback effects between critical infrastructures by using DANP method. Liou (2015) proposed an evaluation system for carbon reduction strategies by using DANP method. Horng, Liu, Chou, Yin, and Tsai (2014) analyzed the most influential factors and their interdependencies by using fuzzy Delphi and DANP methods in the tourism and gourmet business environments. Sangari, Razmi, and Zolfaghari (2015) developed an evaluation model to identify the key factors for achieving supply chain agility by using DANP method. Govindan, Kannan, and Shankar (2014) proposed a methodological framework to evaluate green manufacturing practices by using DANP and PROMETHEE methods. Chuang, Lin, and Chen (2015) applied DANP method to examine

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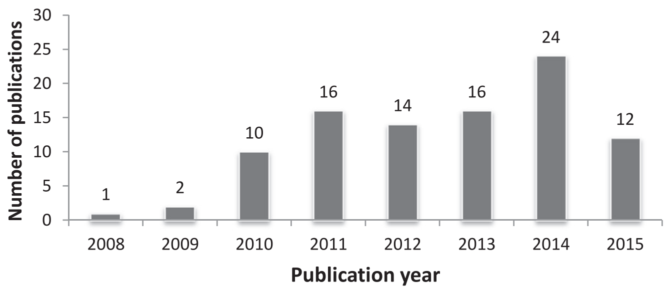

Fig. 13. Annual number of publications on DEMATEL & ANP hybridization.

dynamic nature of organizational value cocreation behavior. Liou, Tamošaitienė, Zavadskas, and Tzeng (2015) proposed a hybrid model by combining DANP and Complex Proportional Assessment of alternatives with Grey relations (COPRAS-G) for improving and selecting suppliers in green supply chain management.

DANP and VIKOR methods were used together for solving variety of MADM problems. Lee (2014) combined DANP and VIKOR method for location selection problem of real estate brokerage services. DANP method was used to obtain influential weights by using the concept of supermatrix formation of the ANP. VIKOR method was employed to incorporate the performance gaps and to rank the alternative location sites. Liu, You, Zhen, and Fan (2014) proposed a hybrid decision making model by using DANP and VIKOR method to solve material selection problem under interdependent criteria. Target-based, cost and benefit criteria were taken into account simultaneously. An empirical case study of the bush material selection for a split journal bearing was provided. Chen (2015) integrated DANP and VIKOR methods for exploring the key factors about the internal control of procurement circulation. Wang, Hsu, and Tzeng (2014) evaluated six sigma projects for reducing performance gaps in each criteria by using DANP and VIKOR. Kuo, Hsu, and Li (2015) assessed green suppliers in an electronics company by using DANP and VIKOR method. Lu et al. (2014) used decomposed theory of planned behavior, DANP and VIKOR method to explore mobile banking services for user behavior in intention adoption. Hu, Lu, and Tzeng (2014) combined DANP and VIKOR methods for exploring the smart phone improvements to add product value to satisfy customer expectations. Liu, Tzeng, and Lee (2013) discussed the connection service between metro systems with urban airports by using DANP and VIKOR methods. An empirical study with the improvement schemes were provided. Hsu, Kuo, Shyu, and Chen (2014) proposed a hybrid model by using fuzzy Delphi, DANP, and VIKOR methods for evaluating the carbon and energy performance of suppliers. An illustrative example from the hotel industry was provided. Lu, Lin, and Tzeng (2013) developed a hybrid MADM approach by using fuzzy DANP and VIKOR for improving green innovation performance. A case study in the electronics industry was conducted. Lee (2013) established a merger and acquisition evaluation model by using DANP and VIKOR method. The performance of three Taiwanese banks were evaluated in the case study. Liu et al. (2013) proposed a hybrid method to improve cruise product sales by combining DANP and VIKOR. Lu et al. (2013) developed an evaluation framework for improvement and adoption of radio frequency identification (RFID) technology by using DANP and VIKOR methods.

4. Bibliometric analysis

Bibliometric analysis is a pragmatic research tool very widely used to discover and detect the state of art in a specific field. The method utilizes quantitative analysis and statistics so as to describe the patterns of publications within a given period or body of literature (Dereli, Baykasoğlu, Altun, Durmuşoğlu, & Türkşen, 2011). Bibliometric analysis is employed by many researchers in order to evaluate a particular field of study or to ascertain the interactions and interrelationships of several distinct fields. Conducting bibliometric analysis generally entails searching for available databases such as Science Citation Index-Expanded, Social Science Citation Index, Arts and Humanities Citation Index and etc. In this line of thought, we conducted a very detailed search from the Thomson Reuters' Web of Science/Knowledge (WoS/K) with Science Citation Index-Expanded (SCI-E), Social Science Citation Index (SSCI) databases. We also utilized Google Scholar and SCOPUS with many keyword combinations to collect all the relevant papers on DEMATEL and ANP applications. Bibliometric analysis we conducted incorporates analysis of number of publications per year, journal titles in which the papers appeared in the literature, the subject area of the papers, top ten authors and affiliations. Main purpose of conducting bibliometric analysis is to provide quantitative measures of the analyzed papers. Recent tendencies, distribution of the articles with respect to different categories, and interactions with the other fields can give further insights for researchers working in this field.

The number of publications appeared in the scientific literature each year is depicted in Fig. 13. As it is seen from the Fig. 15, the first paper was published in 2008. Since the year 2008, the number

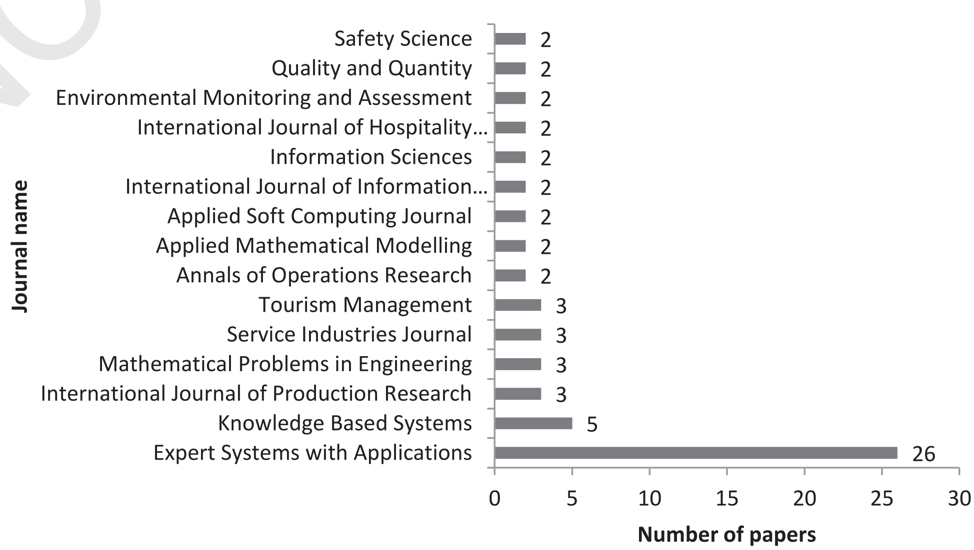

Fig. 14. Number of papers published in certain journals.

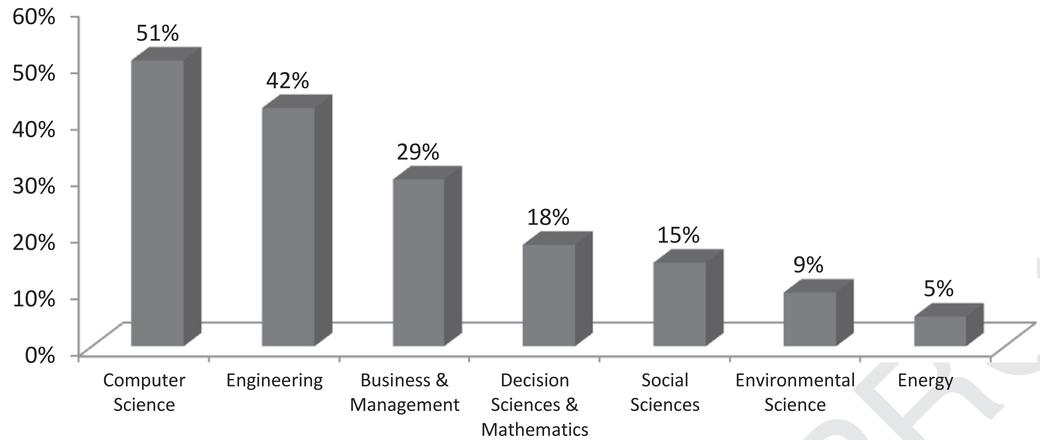

Fig. 15. Percentage of papers with respect to main application areas.

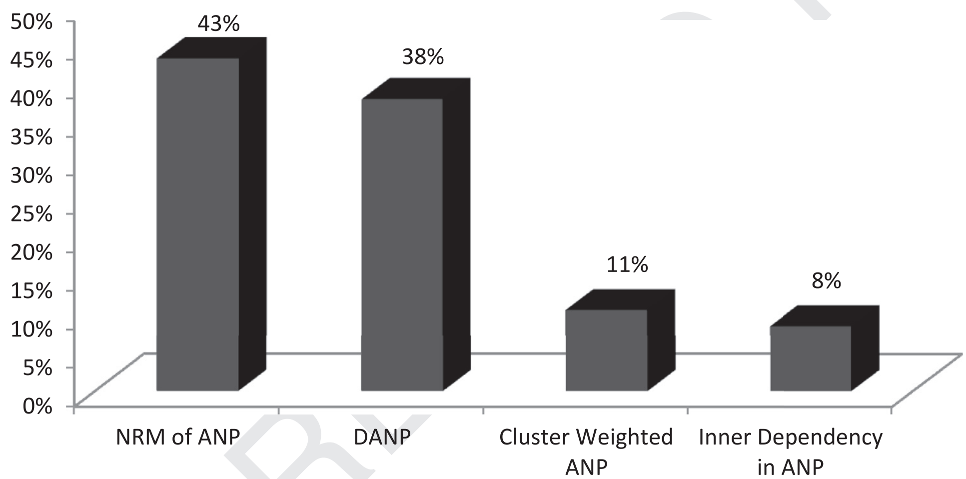

Fig. 16. Percentage of different hybrid techniques among analyzed papers.

of publications has increased considerably within a relatively short period of time.

Papers are published in top scientific journals such as Expert Systems with Applications (26%), Knowledge Based Systems (5%), International Journal of Production Research (3%), Mathematical Problems in Engineering (3%), Service Industries Journal (3%), Information Sciences (2%), Annals of Operations Research (2%). Number of papers published in corresponding scientific journals is depicted in Fig. 14.

Analyzing the published papers, it is observed that they cover very broad range of application areas. Because our aim is to reveal general picture of the application areas, we have chosen general terms to categorize papers as shown in Fig. 15. The subject areas of the papers are mostly accumulated in computer science (51%), engineering (42%), business and management (29%). Subsequently, decision sciences and mathematics (18%), social sciences (15%), environmental science (9%), and energy (5%) are the other application domains.

We also observed that DEMATEL method is mostly used for constructing the NRM of the criteria in the ANP models as shown in Fig. 16. There are 41 papers which accounts for the 43% of the papers employing DEMATEL for establishing NRM. There are 36 papers (38%) which deal with the DANP application. Also 75% of papers (27 out of 36 papers) employing DANP have been published in last two

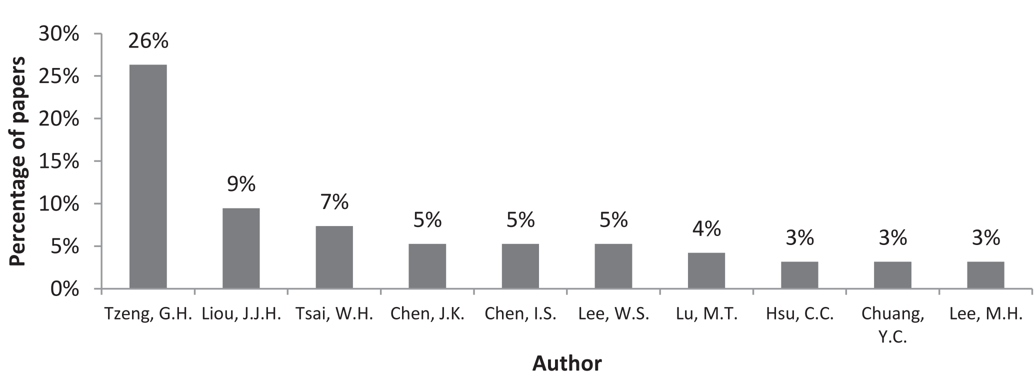

Fig. 17. The most publishing authors.

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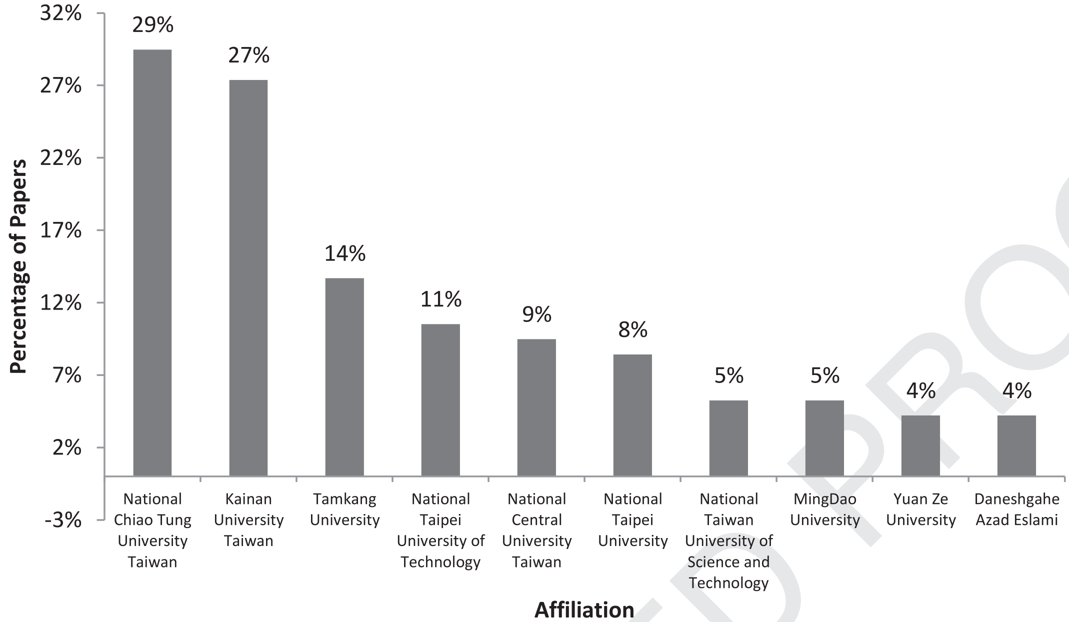

Fig. 18. Top ten affiliations of the papers.

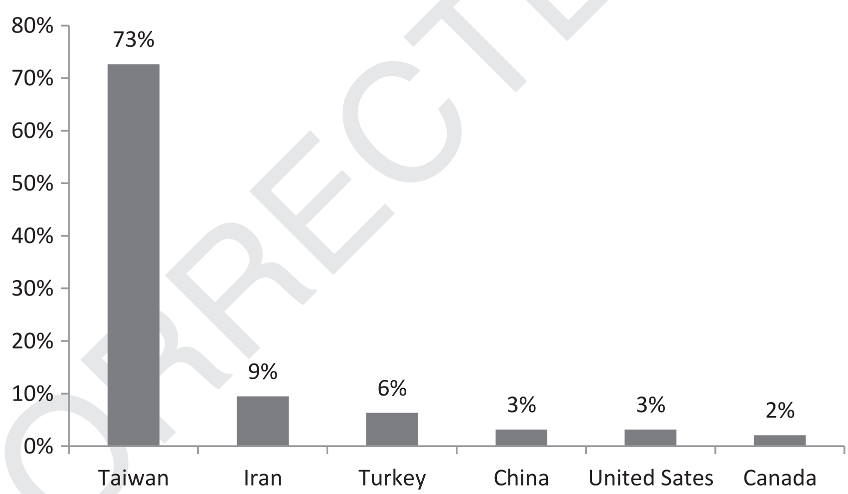

Fig. 19. Country origins of publications.

years. We expect that the DANP method will gain much attention in the coming years. Lastly, 11% of the papers utilized cluster weighted ANP. Similarly, DEMATEL method is used for modeling inner dependency portion of the supermatrix in 8% of papers.

It is observed that Taiwanese researchers have extensively employed the hybrid techniques of DEMATEL and ANP. In Fig. 17, top ten researchers in this field are shown. The most influential authors are the Tzeng (26% of papers), Liou, (9%), Tsai, (%7), Chen, (5%), Chen, (5%), Lee, (5%).

In Fig. 18, the top ten affiliations of the authors are also given. National Chiao Tung University (29%), Kainan University (27%), Tamkang University (14%) are the top three affiliations of the papers. The majority of the affiliations deals with Taiwanese universities.

Analyzing the countries of the authors which are shown in Fig. 19, 73% of the authors are from Taiwan. It is also evident from the fact that the top ten affiliations of the authors are Taiwanese universities, except the Daneshgahe Azad Eslami, which is located in Iran.

Turkey contributed to 6% of the papers in this field. China and the United States contributed to 3% of the papers. Canada have the 2% share of the papers.

5. Concluding remarks

In this paper a comprehensive analysis and review of the DEMATEL and ANP hybrid methods are provided. Four techniques are identified and carefully investigated along with their practical applications. The DEMATEL and ANP hybrid techniques are mainly used for the following needs:

- Identification of criteria structure: The ANP assumes that the criteria structure is known a priori. Despite the strong mathematical underpinnings of the ANP, it does not provide any systematic methodology to generate criteria and clusters, and to identify the corresponding interdependencies. For that reason, DEMATEL method is used to grasp NRM of the problem in most of the studies. We observed that, studies making use of DEMATEL for structuring the problem constitute 43% of the papers. This is the most commonly used way of DEMATEL utilization.
- Pairwise comparisons and survey questions: Especially, eliciting priorities for inner dependencies entails some ambiguous questions to be answered. Pairwise comparisons are, in

general, cognitively demanding. However, when it comes to inner dependency, questions might be nonsense. To overcome this difficulty, inner dependency-related priorities in the supermatrix are calculated by DEMATEL. Since DEMATEL method is based on the cause and effect relationships, constructing direct relation matrix is much more practical. We observed that 8% of the papers make use of DEMATEL for obtaining inner dependency regions of the supermatrix.

- Unequal importance of clusters: In traditional ANP method, clusters are assumed to be equally important. However, clusters might have different priorities. For that reason, influences among clusters are obtained via DEMATEL method. This type of usage provides two important advantages. Firstly, it overcomes the unrealistic assumption of equally important clusters. Secondly, influence degrees among clusters are used to weight the unweighted supermatrix, which leads to weighted supermatrix. All columns of the weighted supermatrix are sum to unity so that it can be raised to large powers to obtain steady state weights. We found that this type of hybridization accounts for the 11% of the papers.
- Practicality concerns: One of the critiques toward ANP is that it is too complex to be applied practically. Researchers realized that the DEMATEL method indeed improves the ANP in terms of many aspects; structuring criteria, overcoming difficult pairwise comparison questions of inner dependencies, and weighting the unweighted supermatrix by unequal influences. In one step forward, DANP method is proposed that brings together all the advantages of other hybrid techniques. In DANP, criteria structure, unweighted supermatrix, and weighted supermatrix are all obtained via DEMATEL method, which is much more practical than traditional ANP. We observed that DANP papers comprise 38% of papers, and we expect growing number of applications of it in the years to follow.

We also observed that the majority of the papers are originated from Taiwan. We expect that these techniques will be applied by researchers from other parts of the world for broader application fields. As a future study, investigating other hybrid techniques of DEMATEL method with other MADM methods would be interesting. We also emphasize that criteria interaction phenomenon is a crucial research topic, and should be investigated in much more detail. It is our belief that research in this direction will bring very interesting insights into the field of decision analysis.

Uncited references

(Baykasoğlu & Durmuşoğlu, 2014, Chen & Chen, 2011, Lee, 2013, Liu et al., 2013, Lu, Tzeng, & Tang, 2013, Lu, Tzeng, Cheng, & Hsu, 2015, Tsai, Leu, Liu, Lin, & Shaw, 2010, Tzeng & Huang, 2012, Uygun, Kaçamak, & Kahraman, 2015, Wu, Chen, & Chen, 2012).

Appendix A. Overview of ANP Method

ANP is one of the most popular MADM methods. It is the generalization AHP which is capable of modeling only static and unidirectional interactions among decision problem components (Sarkis, 1998). However, real life problems are very difficult to be modeled via hierarchical structures, since there are many interactions among the elements of the different levels. Therefore, ANP is pragmatic tool to solve complex decision structures by utilizing the supermatrix formation. The supermatrix or influence matrix can be considered as the generalization of the AHP, since ANP offers much more flexibility for taking complex interactions among different elements into consideration (Saaty, 1996).

Basic steps of the ANP method are as follows (Meade & Sarkis, 1999; Saaty, 1996):

Step 1: Problem structuring and construction of model: Structuring a decision problem is one of the most significant steps in the analysis. The AHP models only deal with the hierarchically structured problems, in which horizontal links are not allowed. On the other hand, the ANP considers problem as a network structure and overcomes the linearity assumption of AHP. Depending on the criteria structure, the supermatrix can take several forms. Saaty (1996) mentioned different structures, such as hierarchy, holarchy, intarchy and so on.

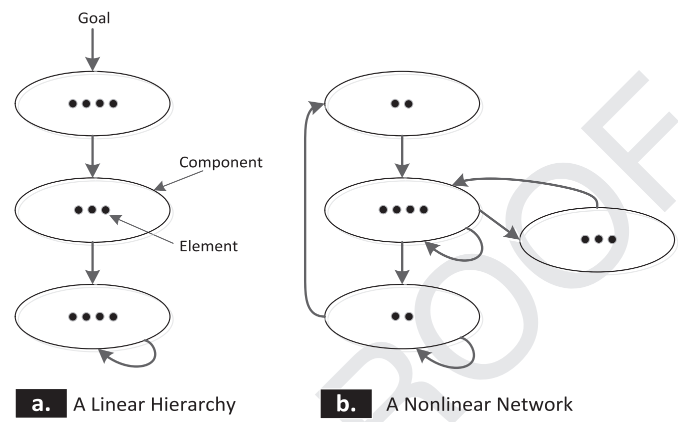

Fig. A.1. Structural difference between a linear hierarchy and a nonlinear network.

Step 2: Pairwise comparison matrices and priority vectors: Once the structure of the problem is identified, decision makers are asked to respond a series of questions to fill out the pairwise comparison matrices. The relative importance of criteria can be calculated based on different prioritization methods, such as eigenvalue method (Saaty, 1977), logarithmic least-squares method (Crawford & Williams, 1985), weighted least-squares method (Chu, Kalaba, & Spingarn, 1979), logarithmic goal programming method (Bryson, 1995), and etc. Fig. A.1.

Step 3: Supermatrix formation: The influences among elements of each node on the other nodes in the network are gathered in a supermatrix (Saaty, 2001). In other words, the relative importance degrees obtained from pairwise comparisons are place into appropriate columns of the supermatrix. The general form of a supermatrix is shown in Eq. A.1, C_n denotes the nth cluster, e_{nm} denotes mth element in the nth cluster, and $\boldsymbol{W}_{ij}$ is the priority vector of the influence of the elements compared in the jth cluster to the ith cluster.

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{ccccc} C_1 & & C_k & & C_n \\ e_{11} \cdots e_{1m_1} \cdots & & e_{j1} \cdots e_{jm_j} \cdots & & e_{n1} \cdots e_{nm_n} \end{array} \\ \begin{array}{c} C_1 \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{array} \\ \vdots \\ C_i \begin{array}{c} e_{i1} \\ e_{i2} \\ \vdots \\ e_{im_i} \end{array} \\ \vdots \\ C_n \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm_n} \end{array} \end{array} & \begin{bmatrix} \boldsymbol{W}_{11} & \cdots & \boldsymbol{W}_{1j} & \cdots & \boldsymbol{W}_{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}_{i1} & \cdots & \boldsymbol{W}_{ij} & \cdots & \boldsymbol{W}_{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{W}_{n1} & \cdots & \boldsymbol{W}_{nj} & \cdots & \boldsymbol{W}_{nn} \end{bmatrix} \end{array} \tag{A.1}$$

The goals, criteria and alternatives are placed in the rows and columns of the supermatrix. The order of elements in the supermatrix is irrelevant. If there is no dependency between nodes, zero is entered.

Step 4: Final priorities and selection of best alternatives: Once the unweighted supermatrix is constructed, it is transformed into the weighted supermatrix by satisfying that all the columns are sum to unity. Next, the weighted supermatrix is raised to limiting powers to obtain global priorities using the Equation A.2:

$$\lim_{k \to \infty} \boldsymbol{W}^k \tag{A.2}$$

If there are two or more limiting supermatrices, the Cesaro sum is used to calculate the final priorities. The Cesaro sum is formulated as follows (Tzeng & Huang, 2011):

$$\lim_{k\to\infty}\left(\frac{1}{N}\right)\sum_{r=1}^{N}\boldsymbol{W}_r^k \tag{A.3}$$

where N denotes number of limiting supermatrices, and $\boldsymbol{W}_r$ denotes the rth limiting priority. Casero sum is used to calculate the average influences of the limiting supermatrix. Finally, the alternative with the largest priority is selected.

Appendix B. Overview of DEMATEL Method

DEMATEL method was established at Battelle Memorial Institute of Geneva Research Center during the research of understanding and solving the intertwined real world problems such as population and hunger, environmental issues, and energy (Gabus & Fontela, 1973). DEMATEL method takes into account the subjective perceptions of individuals and captures the analyst's insight into the complex problem on hand. The aim of DEMATEL is to reveal direct/indirect causal relations (dependencies) among system variables. Steps of the DEMATEL method are as follows (Lee, Li, Yen, & Huang, 2010):

Step 1: Definition of variables and establishment of measuring scale: Brainstorming-like methods with the help of literature discussion are used to define variables influencing the complex system. Also a measuring scale is established in this step. Distinct measuring scales are used by different researchers in the literature. 3-point scale (Lin & Wu, 2008), 4-point scale (Yang & Tzeng, 2011), 5-point scale (Kim, 2006), 10-point scale (Huang, Shyu, & Tzeng, 2007) are some of the examples.

Step 2: Establishing the direct-relation matrix: The direct-relation matrix $\boldsymbol{A} = [a_{ij}]_{n\times n}$is constructed. Here, a_{ij} represents the influence of criterion/cluster a_i on criterion/clustera_j, and n is the number of criteria.

$$\boldsymbol{A} = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix} \tag{B.1}$$

Step 3: Calculating normalized direct-relation matrix: Once the direct-relation matrix is established, normalization is applied. A commonly used method for normalization is employing the normalization factor given by Eq. B.2 (Tzeng, Chiang, & Li, 2007)

$$s = \text{Min}\left[\frac{1}{\text{Max}_{1\le i\le n}\left(\sum_{j=1}^{n} a_{ij}\right)}, \frac{1}{\text{Max}_{1\le j\le n}\left(\sum_{i=1}^{n} a_{ij}\right)}\right] \tag{B.2}$$

where s is the normalization factor. The normalized direct-relation matrix, denoted by $\boldsymbol{X}$ is calculated by multiplying the direct-relation matrix $\boldsymbol{A}$ by s as given in Equation B.3:

$$\boldsymbol{X} = s \times \boldsymbol{A} \tag{B.3}$$

Step 4: Calculate direct/indirect relation matrix. The direct/indirect relation matrix, known as total relation matrix, can be calculated as follows (Huang et al., 2007):

$$\boldsymbol{T} = \lim_{k\to\infty}\left(\boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^k\right) = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1} \tag{B.4}$$

where $\boldsymbol{T}$ denotes the total relation matrix. In total relation matrix, influence of ith criterion/cluster on the jth criterion/cluster is denoted by t_{ij}. Another very important feature of DEMATEL method is that the most affecting and the most affected factors can be visualized. After the total relation matrix $\boldsymbol{T}$ is calculated, the sum of the row and column values can be obtained. Sum of row values of $\boldsymbol{T}$, denoted by $\boldsymbol{D}$, is formally expressed as given in Eq. B.5:

$$\boldsymbol{D} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \quad (i = 1, 2, \ldots, n) \tag{B.5}$$

Sum of the row values implies the overall influence of a given factor on other factors. In addition to sum of row values of $\boldsymbol{T}$, the sum of column values of $\boldsymbol{T}$, denoted by $\boldsymbol{R}$, can be calculated as given in Eq. B.6:

$$\boldsymbol{R} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n}, \quad (j = 1, 2, \ldots, n) \tag{B.6}$$

A sum of the column values implies the overall influence of other factors on a given factor.

Furthermore, a visual causal diagram can be depicted by calculation of $(\boldsymbol{D}+\boldsymbol{R})$ and $(\boldsymbol{D}-\boldsymbol{R})$ values. The $(\boldsymbol{D}+\boldsymbol{R})$values are placed to x axis and called prominence. Prominence values indicate how important the criteria are. On the other hand, the $(\boldsymbol{D}-\boldsymbol{R})$ values are arranged in y axis and called relation. The relation values enable factors to be separated into cause and effect groups. If relation value of a criterion is positive, then it belongs to cause group. Otherwise, criterion belongs to effect group.

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