Review Article

DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications

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Decision making trial and evaluation laboratory (DEMATEL) is considered as an effective method for the identification of cause-effect chain components of a complex system. It deals with evaluating interdependent relationships among factors and finding the critical ones through a visual structural model. Over the recent decade, a large number of studies have been done on the application of DEMATEL and many different variants have been put forward in the literature. The objective of this study is to review systematically the methodologies and applications of the DEMATEL technique. We reviewed a total of 346 papers published from 2006 to 2016 in the international journals. According to the approaches used, these publications are grouped into five categories: classical DEMATEL, fuzzy DEMATEL, grey DEMATEL, analytical network process- (ANP-) DEMATEL, and other DEMATEL. All papers with respect to each category are summarized and analyzed, pointing out their implementing procedures, real applications, and crucial findings. This systematic and comprehensive review holds valuable insights for researchers and practitioners into using the DEMATEL in terms of indicating current research trends and potential directions for further research.

1. Introduction

Decision making trial and evaluation laboratory (DEMATEL) technique was first developed by the Geneva Research Centre of the Battelle Memorial Institute to visualize the structure of complicated causal relationships through matrixes or digraphs [1]. As a kind of structural modeling approach, it is especially useful in analyzing the cause and effect relationships among components of a system. The DEMATEL can confirm interdependence among factors and aid in the development of a map to reflect relative relationships within them and can be used for investigating and solving complicated and intertwined problems. This method not only converts the interdependency relationships into a cause and effect group via matrixes but also finds the critical factors of a complex structure system with the help of an impact relation diagram.

Due to its advantages and capabilities, the approach of DEMATEL has received a great deal of attention in the past decade and many researchers have applied it for solving complicated system problems in various areas. In addition, the DEMATEL has been extended for better decision making under different environments since many real-world systems include imprecise and uncertain information. However, to the best of our knowledge, no systematic review has been performed for the DEMATEL technique and its applications. Therefore, in this study, we present a comprehensive review of the state-of-the-art literature regarding the approaches to decision making based on the DEMATEL. As a result of search using the Scopus database and following a methodological decision analysis, a total of 346 papers published in scientific journals from 2006 to 2016 were reviewed in detail. Based on the selected articles, the main objectives of this review are as follows: (1) to summarize the DEMATEL methods that have been used in the academic literature, (2) to reveal the different usage and application areas of these approaches, (3) to show the current research trends in this field of study, and (4) to find out the potential research directions in the future.

The remaining part of this paper is structured as follows: In Section 2, we introduce the research methodology used to identify and refine the literature in this study. In Section 3, detailed reviews of each category of the DEMATEL studies are presented. Section 4 describes some general observations and findings based on statistical analysis results of the review. Finally, this paper concludes in Section 5 by summarizing the results and discussing opportunities for future research.

2. Research Methodology

For the purpose of this literature review, we searched for articles in the Scopus database published between 2006 and 2016. The choice of this time period is based on the fact that the majority of papers on this topic were published during this period and there are only five articles recorded in the Scopus prior to 2006. Inspired by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISRMA) method [2, 3], the selection of articles in this study is consisted of three stages, that is, literature search, articles eligibility, and data extraction and summarizing. First, the keyword "DEMATEL" was used for searching in "abstract, title, and keywords" for journal papers, and a total of 509 document results were identified from Scopus. Next, we chose the articles which had used the DEMATEL technique or its extensions to solve real-world problems, and 346 academic papers fell under the scope of this review after title, abstract, and full-text screening. Since this study focuses on both the DEMATEL and its applications, those studies which only modify the DEMATEL technique without applying to actual settings have been eliminated (for the interested readers, please refer, e.g., to [4–6]). Finally, the resulting papers were reviewed thoroughly to identify the focus, method, application, and combination with other methods. Also articles were summarized based on various criteria such as year of publication, application areas, and citations.

Based on the DEMATEL methods adopted, the selected publications are roughly grouped into five categories: the ones using classical DEMATEL (105 articles), the ones using fuzzy DEMATEL (63 articles), the ones using grey DEMATEL (12 articles), the ones combining analytical network process (ANP) and DEMATEL (154 articles), and the ones based on other DEMATEL methods (12 articles). The classification scheme of the DEMATEL articles is shown in Figure 1. Most of the papers on ANP and DEMATEL hybridization are included in a review paper of DEMATEL approaches for criteria interaction handling with ANP by Gölcük and Baykasoğlu [7]. Therefore, in the following sections, we will not discuss the studies which apply the DEMATEL in conjunction with ANP to deal with interactions among criteria.

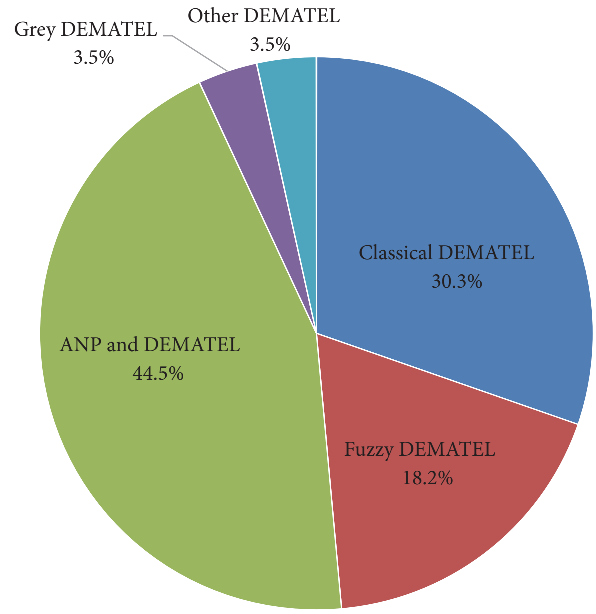

Figure 1: Classification scheme of the DEMATEL articles.

3. Reviews of DEMATEL Methods

3.1. The Classical DEMATEL. As stated earlier, the DEMATEL technique can convert the interrelations between factors into an intelligible structural model of the system and divide them into a cause group and an effect group [8]. Hence, it is an applicable and useful tool to analyze the interdependent relationships among factors in a complex system and rank them for long-term strategic decision making and indicating improvement scopes. The formulating steps of the classical DEMATEL can be summarized as follows [8–10].

Step 1 (generate the group direct-influence matrix Z). To assess the relationships between n factors $F = \{F_1, F_2, \dots, F_n\}$ in a system, suppose that l experts in a decision group $E = \{E_1, E_2, \dots, E_l\}$ are asked to indicate the direct influence that factor F_i has on factor F_j, using an integer scale of "no influence (0)," "low influence (1)," "medium influence (2)," "high influence (3)," and "very high influence (4)." Then, the individual direct-influence matrix $Z_k = [z_{ij}^k]_{n\times n}$ provided by the kth expert can be formed, where all principal diagonal elements are equal to zero and z_{ij}^k represents the judgment of decision maker E_k on the degree to which factor F_i affects factor F_j. By aggregating the l experts' opinions, the group direct-influence matrix $Z = [z_{ij}]_{n\times n}$ can be obtained by

$$z_{ij} = \frac{1}{l}\sum_{k=1}^{l} z_{ij}^k, \quad i, j = 1, 2, \dots, n. \tag{1}$$

Step 2 (establish the normalized direct-influence matrix X). When the group direct-influence matrix Z is acquired, the normalized direct-influence matrix $X = [x_{ij}]_{n\times n}$ can be achieved by using

$$X = \frac{Z}{s}, \tag{2}$$

$$s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}, \max_{1\le i\le n}\sum_{i=1}^{n} z_{ij}\right). \tag{3}$$

All elements in the matrix X are complying with $0 \le x_{ij} < 1$, $0 \le \sum_{j=1}^{n} x_{ij} \le 1$, and at least one i such that $\sum_{j=1}^{n} z_{ij} \le s$.

Step 3 (construct the total-influence matrix T). Using the normalized direct-influence matrix X, the total-influence matrix $T = [t_{ij}]_{n\times n}$ is then computed by summing the direct effects and all of the indirect effects by

$$T = X + X^2 + X^3 + \cdots + X^h = X(I - X)^{-1}, \quad \text{when } h \longrightarrow \infty, \tag{4}$$

in which I is denoted as an identity matrix.

Step 4 (produce the influential relation map (IRM)). At this step, the vectors R and C, representing the sum of the rows and the sum of the columns from the total-influence matrix T, are defined by the following formulas:

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1}, \qquad C = [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]^{T}_{1\times n}, \tag{5}$$

where r_i is the ith row sum in the matrix T and displays the sum of the direct and indirect effects dispatching from factor F_i to the other factors. Similarly, c_j is the jth column sum in the matrix T and depicts the sum of direct and indirect effects that factor F_j is receiving from the other factors.

Let $i = j$ and $i, j \in \{1, 2, \ldots, n\}$; the horizontal axis vector $(R + C)$ named "Prominence" illustrates the strength of influences that are given and received of the factor. That is, $(R + C)$ stands for the degree of central role that the factor plays in the system. Alike, the vertical axis vector $(R-C)$ called "Relation" shows the net effect that the factor contributes to the system. If $(r_j - c_j)$ is positive, then the factor F_j has a net influence on the other factors and can be grouped into cause group; if $(r_j - c_j)$ is negative, then the factor F_j is being influenced by the other factors on the whole and should be grouped into effect group. Finally, an IRM can be created by mapping the dataset of $(R+C, R-C)$, which provides valuable insights for decision making.

3.1.1. Observations and Findings. Table 1 summarizes all the classical DEMATEL studies based on the particular purpose of using DEMATEL, the topic of decision making, and other methods combined. According to the distinct usage of the DEMATEL method, the current classical DEMATEL researches can be classified into three types: the first type is merely clarifying the interrelationships between factors or criteria; the second type is identifying key factors based on the causal relationships and the degrees of interrelationship between them; the third type is determining criteria weights by analyzing the interrelationships and impact levels of criteria.

In Table 1, we have provided an overview on the existing applications of the classical DEMATEL for solving complicated and intertwined problems in many fields, based on which we now point out some critical steps added to the original approach.

Step 4-1 (set a threshold value to draw the IRM). In the above, the IRM is constructed based on the information from the matrix T to explain the structure relations of factors. But, in some situations, the IRM will be too complex to show the valuable information for decision making if all the relations are considered. Therefore, a threshold value θ is set in many studies to filter out negligible effects. That is, only the element of matrix T, whose influence level is greater than the value of θ, is selected and converted into an IRM.

If the threshold value is too low, many factors are included and the IRM will be too complex to comprehend. In contrast, some important factors may be excluded if the threshold value is too high. In the literature, the threshold value θ is usually determined by experts through discussions [10, 11], the results of literature review, the brainstorming technique [12], the maximum mean deentropy (MMDE) [13], the average of all elements in the matrix T [14], or the maximum value of the diagonal elements of the matrix T [15].

Step 4-2 (obtain the inner dependence matrix T'). When the total-influence matrix T is produced, in [16, 17], an inner dependence matrix T' is acquired by normalizing the matrix T so that each column sum is equal to 1. But, in [18], the inner dependence matrix T' is derived based on the threshold value θ and only the factors whose effects in the matrix T are larger than θ are shown in the matrix T'.

To interpret the results easily and keep the complexity of the system manageable, Tzeng [19] established a simplified normalized total-influence matrix $\widehat{T}^s$ using a normalization method and the threshold value θ. First, the normalized total-influence matrix $\widehat{T} = [\widehat{t}_{ij}]_{n\times n}$ is calculated by using (6) to force the values of the matrix T within the scope of a measurement scale.

$$\widehat{t}_{ij} = \frac{(k - 0)\left(t_{ij} - \min t_{ij}\right)}{\max t_{ij} - \min t_{ij}}, \tag{6}$$

where k is the highest score for measuring the degree of relative impact between factors and $k = 4$ if the integral scale of 0 to 4 is used. Then, the simplified normalized total-influence matrix $\widehat{T}^s = [\widehat{t}^s_{ij}]_{n\times n}$ is obtained by eliminating insignificant effects in the matrix $\widehat{T}$ based on the threshold value θ. That is,

$$\widehat{t}^s_{ij} = \begin{cases} \widehat{t}_{ij} & \text{if } \widehat{t}_{ij} > \theta \\ 0 & \text{if } \widehat{t}_{ij} \le \theta. \end{cases} \tag{7}$$

Step 4-2' (divide the IRM into four quadrants). Once an IRM is acquired, eight of the classical DEMATEL studies classified the factors in a complicated system into four quadrants according to their locations in the diagram. In [20–22], the IRM is divided into four quadrants I to IV, as displayed in

Table 1: Various applications of the classical DEMATEL.

Papers	Research purposes	Combinations	Remarks
	Type 1: interrelationships		
B. Efe and Ö. F. Efe [42]	Specify the influence degrees of the patient perceived values when applying lean health-care management in an emergency department		Threshold value-average
Malekzadeh et al. [43]	Investigate the cause and effect relations for the dimensions and components of organizational intelligence in Iranian public universities		Threshold value
Ranjan et al. [44]	Address the interrelationships between different evaluation criteria of Indian Railway zones	VIKOR	Threshold value-average
Tzeng et al. [10]	Address the dependent relations of evaluation criteria and propose a hybrid MCDM model for evaluating intertwined effects in e-learning programs	FA, AHP, fuzzy integral	Threshold value-experts
Hu et al. [45]	Establish the causal relationship and extent of mutual impact among quality features and put forth a decision analysis methodology to remove potential problems from the conventional IPA model	BPNN	
Hu et al. [46]	Analyze the cause-effect relationship among different quality characteristics to make revisions to the traditional IPA model and find the core problems involved with winning orders	GA, MRA	
Cheng et al. [47]	Explore the connection between service quality attributes and the service quality improvement priority of fine-dining restaurants and use it as a reference for service quality strategy planning and resource reorganizing	IPGA	
Hsieh and Yeh [48]	Examine cause and effect relations of factors influencing the service quality in fast food restaurants		Threshold value-average
Chiu et al. [49]	Analyze relationships of customer buying decision factors and provide a marketing strategy planning for firms in the LCD-TV market		
Ho et al. [50]	Analyze the cause-effect relation between quality characteristics and build a methodology of supplier quality performance assessment to improve supplier quality through optimizing order-winners and qualifiers	IPA, MRA	
Tsai et al. [51]	Determine the causal relationships of and interactive influence among criteria and propose a mixed model to evaluate job satisfaction in high-tech industries	IPA	
Najmi and Makui [52]	Understand the relationship between comparison metrics and propose a conceptual model for measuring supply chain performance	AHP	
Shafiee et al. [53]	Determine the relationships between four perspectives of BSC and propose an approach to evaluate the performance of supply chain	DEA, BSC	Threshold value-average
Shaik and Abdul-Kader [16]	Understand the interdependence among performance factors and develop a reverse logistics enterprise performance measurement model	BSC	Inner dependence matrix

Table 1: Continued.

Papers	Research purposes	Combinations	Remarks
Lin and Tzeng [11]	Determine the relationship between the evaluation criteria contributing industry clusters and establish their value structures and build a value-created system of science (technology) park		Threshold value-experts
Lin and Sun [18]	Examine the impacts of and determine the relationships among different driving forces for the growth of industrial clusters		Threshold value-experts/inner dependence matrix
Wang and Hsueh [54]	Recognize the causal relationships between design attributes and marketing requirements and propose an approach to incorporate customer preference and perception into product development	AHP, Kano model	
Wang and Shih [55]	Identify the impacts of functional attributes on customer requirements and present a framework to incorporate customer preferences into product development	CA1, QFD, TOPSIS	
Ko et al. [56]	Analyze direct and indirect impacts among various technology areas and present a combined approach to construct technology impact networks for R&D planning using patents	SNA	
Yoon et al. [57]	Assess technological impacts and degree of cause or effect among technology areas within the Korean technology system and observe their dynamic trends	PCCA	
Shen and Tzeng [58]	Explore the cause-effect relationships among the attributes in the strong decision rules and propose a model for tackling the value stock selection problem	DRSA, FCA	
Altuntas and Dereli [59]	Establish causal relationships among technologies and propose an approach for prioritizing investment projects from the government's perspective	PCA	Threshold value-average
Shen and Tzeng [60]	Explore the complex relationship among financial indicators and improve future financial performance of the IT industry	VC-DRSA, FIS	
Lee and Lin [13]	Find the interrelationship of financial ratios identified by managers of shipping companies and financial experts and compare their cognition maps by country and expert group		Threshold value-MMDE
W.-K. Tan and Y.-J. Tan [61]	Analyze how different factors interact and collectively contribute to the successful transformation and diffusion of the smart-card-based e-micropayment multipurpose scheme		
Azadeh et al. [12]	Evaluate the impact degree of leanness factors and presents a comprehensive approach for evaluating and optimizing the leanness degree of organizations (lean production)	DEA, fuzzy DEA, FCM, AHP	Threshold value-average
Sara et al. [14]	Assess relative importance and mutual influence of barriers for carbon capture and storage deployment	AHP	Threshold value-average
Liaw et al. [62]	Analyze the indirect relations between subsystems and components and propose a reliability allocation method to solve the fundamental problems of conventional reliability apportionment methods	ME-OWA	
	Type 2: interrelationships and key factors		
Alaei and Alroaia [63]	Identify and prioritize the factors affecting and affected by the performance of small and medium enterprises		
Bacudio et al. [64]	Analyze cause-effect relationships of barriers to implementing industrial symbiosis networks in an industrial park		Threshold value-average/inner dependence matrix
Balkovskaya and Filneva [65]	Identify causal relationships between the key evaluation indicators of banking performance as well as defining the most strategically important indicators	BSC	Threshold value-second quartile

Table 1: Continued.

Papers	Research purposes	Combinations	Remarks
Chen [66]	Estimate the importance of the service factors of an academic library and identify the causal factors		Threshold value-experts
Govindan and Chaudhuri [67]	Analyze the risks faced by third-party logistics service providers in relation to one of its customers and extract the causal relationships among them		
Govindan et al. [68]	Investigate the influential strength of factors on adoption of green supply chain management practices in the Indian mining industry	AHP	Threshold value-average
Gandhi et al. [69]	Evaluate success factors in implementation of green supply chain management in Indian manufacturing industries		
Hwang et al. [70]	Explore the causal relationships among decision factors relating to green supply chains in the semiconductor industry		
Hwang et al. [71]	Identify determinants and their causal relationships affecting the adoption of cloud computing in science and technology institutions		Threshold value-$\mu + 3/2\sigma$
Hwang et al. [20]	Assess the dynamic risk interdependencies for distinct project phases and identify critical risk factors		Threshold value-experts
Rahimnia and Kargozar [72]	Discover causal relationships between objectives in university strategy map and prioritize them for resource allocation	BSC	Threshold value-third quartile
Sekhar et al. [73]	Prioritize and map the causal relation structures in dimensions and subdimensions of HR-flexibility and firm performance from IT industry perspective		
Seleem et al. [74]	Select and manage the suitable performance improvement initiatives to enhance the internal processes of manufacturing companies	BSC, TOC	Rank based on R and C
Sharma et al. [75]	Assess the causal relationships among lean criteria and identify critical ones for the successful implementation of lean manufacturing		Threshold value-average
Shen [76]	Identify the key barriers and their interrelationships impeding the university technology transfer from a multistakeholder perspective		Threshold value-third quartile
Seyed-Hosseini et al. [77]	Analyze the relation between components of a system and propose a methodology for reprioritization of failure modes in FMEA		Rank based on $R - C$
Chang [78]	Analyze the relationship between components of a system and outline a general algorithm for prioritization of failure modes in FMEA	OWGA	Rank based on $R - C$
Chang et al. [79]	Examine the direct and indirect relationships between failure modes and causes of failure and propose an approach to rank the risk of failures	GRA	Rank based on $R - C$
Chang et al. [80]	Examine the direct and indirect relationships between failure modes and causes of failure and propose an approach to rank the risk of failures	TOPSIS	Rank based on $R - C$

Table 1: Continued.

Papers	Research purposes	Combinations	Remarks
Liu et al. [81]	Construct the influential relations among failure modes and causes of failures and develop a framework for prioritization of failure modes	AHP, VIKOR	
Mentes et al. [82]	Consider the direct-indirect relationships between factors and propose an integrated methodology for risk assessment of cargo ships at coasts and open seas	OWGA	
Huang et al. [8]	Identify major industry innovation requirements and present reconfigured innovation policy portfolios to develop Taiwan's SIP Mall industry	GRA, CA1	Threshold value-experts
Li and Tzeng [9]	Discover and illustrate the key services needed to attract SIP users and SIP providers to an SIP Mall		Threshold value-experts
Horng et al. [83]	Identify the relationships and interactions among dimensions of restaurant space design from the expert's perspective		Threshold value-average
Chen et al. [84]	Determine critical core factors affecting consumer intention to dine at green restaurants and develop specific improvement strategies	SEM, QFD	
Cheng et al. [85]	Develop a three-tiered service quality improvement model to identify critical educational-service-quality deficiencies in hospitality, tourism, and leisure undergraduate programs	IPGA, QFD	
Shieh et al. [86]	Evaluate the importance and construct the causal relations of criteria from patients' viewpoints and identify key success factors for improving the hospital service quality	SERVQUAL model	Threshold value-average
Ranjan et al. [87]	Analyze and explain the interaction relationships and impact levels between evaluation criteria and develop a framework for performance evaluation of engineering departments in a university	VIKOR, entropy method	Threshold value-average
Tan and Kuo [15]	Prioritize facilitation strategies of rural park and recreation agencies from the perspective of leisure constraints		Threshold value-maximum value
Wu et al. [88]	Describe the contextual relationships evaluated among criteria and evaluate the importance of the criteria used in employment service outreach program personnel		Threshold value-average
Sun [89]	Handle the inner dependence and identify core competences of newly qualified nurses		Threshold value-experts
Wu and Tsai [90]	Describe the contextual relationships among the criteria and evaluate the importance of dimensions/criteria in auto spare parts industry		Threshold value-average

TABLE 1: Continued.

Papers	Research purposes	Combinations	Remarks
Sun [91]	Identify and analyze critical success factors in the electronic design automation industry		Threshold value-experts
Wu and Tsai [92]	Depict the causal relations and evaluate the importance of criteria in auto spare parts industry	AHP	Threshold value-average
Wei et al. [93]	Reprioritize the amended modes in the SEM model and establish a causal relationship model for Web-advertising effects		
Wu et al. [24]	Explore the factors hindering the acceptance of using internal cloud services in a university	TAM	Four quadrants
Hsu [94]	Find the determinant factors influencing blog design and simplify and visualize the interrelationships between criteria for each factor	FA	Threshold value-experts
Hsu and Lee [95]	Explore the critical factors influencing the quality of blog interfaces and the causal relationships between these factors		
Lee et al. [96]	Establish the causal relationship and the degree of interrelationship of DTPB variables (university library website)		
Wu et al. [23]	Explore decisive factors affecting an organization's Software as a Service (SaaS) adoption		Four quadrants
Pathari and Sonar [97]	Analyze a set of security statements in information security policy, procedures, and controls to establish an implicit hierarchy and relative importance among them		
Jafarnejad et al. [98]	Classify the criteria in ERP selection into the two groups of "cause" and "effect" and propose a combined MCDM approach to select the proper ERP system	Entropy method, fuzzy AHP	
Tsai and Cheng [99]	Analyze KPIs for E-commerce and Internet marketing of elderly products	BSC	
Wang et al. [25]	Capture the causal relationships among divisions and identify those divisions within a matrix organization that may be responsible for the poor performance of a high-tech facility design project	SIA	Net influence matrix
Lin et al. [100]	Explore the core competences and investigate their cause and effect relationships of the IC design service company		Threshold value-experts
Chuang et al. [21]	Investigate the complex multidimensional and dynamic nature of member engagement behavior in environmental protection virtual communities	ISM	Threshold value-experts/four quadrants
Rahman and Subramanian [101]	Identify critical factors for implementing EOL computer recycling operations in reverse supply chain and investigate the causal relationship among the factors		Threshold value-average
Hsu et al. [102]	Recognize the influential criteria of carbon management in green supply chain to improve the overall performance of suppliers		Threshold value
Falatoonitoosi et al. [103]	Examine complex causal relationship between factors in green supply chain management and provide an evaluation framework to select the most eligible green suppliers		
Ren et al. [104]	Identify key driving factors and map their cause-effect relationships for enhancing the sustainability of hydrogen supply chain		Threshold value-experts
Muduli and Barve [105]	Extract the causal relationships among green supply chain management barriers and establish a sustainable development framework in scale Indian mining industries		

Table 1: Continued.

Papers	Research purposes	Combinations	Remarks
Wu and Chang [106]	Identify the critical dimensions and factors to implement green supply chain management in the electrical and electronic industries		Threshold value-average
Behera and Mukherjee [107]	Capture relationships and analyze key influencing factors relevant to selection of supply chain coordination schemes		Threshold value-MMDE
Ahmed et al. [108]	Select the most important dimensions and criteria for evaluating sustainable EOL vehicle management alternatives	Fuzzy AHP	
Ahmed et al. [109]	Select the most important dimensions and criteria and propose an integrated model for sustainable EOL vehicle management alternative selection	AHP, fuzzy AHP	
Miao et al. [110]	Evaluate the importance and unveil the implicit interrelationships among different scales of CPV and construct a multiscale model for the measurement of CPV of EVs	HoQ	Threshold value-experts/rank based on $R + C$
Lin [111]	Analyze interactions among industrial development factors and explore how to establish the competitiveness of solar photovoltaic industry	Porter's Diamond model	
Azarnivand and Chitsaz [112]	Quantify the interlinkages among fundamental anthropogenic indicators and propose a systematic approach for water shortage mitigation in the arid regions	eDPSIR, AHP, COPRAS-G	
Chen et al. [113]	Quantify the influence on PM2.5 by other factors in the weather system and identify the most important factors for PM2.5	RM	Four quadrants
dos Muchangos et al. [114]	Assess the barriers to municipal solid waste management policy planning and identify the most onerous barriers to the effective implementation of the policy	ISM	Net influence matrix
Guo et al. [115]	Evaluate and investigate green corporate CSR indicators of manufacturing corporations from a green industry law perspective		Four quadrants
Chen and Chi [116]	Explore key factors of China's CSR from the perspective of accounting experts		
Chang et al. [117]	Identify key strategic factors in the implementation of CSR in airline industry		
Lee et al. [118]	Calculate the causal relationship and interaction level between TAM variables and find the core variables for management or improvement while introducing a new etching plasma technology		Four quadrants
Wu [119]	Determine the causal relationships between the KPIs of the BSC and link them into a strategy map for banking institutions	BSC	
Chien et al. [22]	Identify relationships between risk factors and assess critical risk factors for BIM projects		Four quadrants

TABLE 1: Continued.

Papers	Research purposes	Combinations	Remarks
Wang et al. [26]	Evaluate the performance of design delay factors and identify key factors that drive design delays of a facility construction project	ISA	Net influence matrix
Tzeng [19]	Investigate the relationship between factors affecting parole boards' decision making in Taiwan		Simplified normalized total-relation matrix/threshold value
Gazibey et al. [120]	Analyze the cause and effect relations among the criteria affecting main battle tank selection		Threshold value-average
Type 3: interrelationships and criteria weights			
Khalili-Damghani et al. [121]	Determine the relative importance weights of compensatory objective functions and propose a hybrid multiple objective metaheuristic algorithm to solve land-use suitability analysis and planning problem	AHP	
Khazai et al. [29]	Analyze direct and indirect dependencies within social and industrial vulnerability indicators and develop a framework for spatial assessment of industrial and social vulnerability to indirect disaster losses		Threshold value/dependency weights
Tseng [122]	Resolve criteria interdependency relationships weights and propose a hybrid method to evaluate service quality expectation in hot spring hotel's ranking problem	Fuzzy TOPSIS	Inner dependence matrix
Quader et al. [123]	Determine the cause and effect relationships among criteria and evaluate the critical criteria for CO2 capture and storage in the iron and steel industry		Criteria weights-vector length/threshold value
Quader and Ahmed [124]	Identify critical factors for evaluating alternative iron-making technologies with carbon capture and storage systems	Fuzzy AHP	Criteria weights-vector length/threshold value
Seyedhosseini et al. [17]	Identify the cause and effect relationships among lean objectives and proposed a systematic & logical method for auto part manufacturers to determine the company's lean strategy map	BSC	Inner dependence matrix/weights-$R + C$
Cebi [27]	Determine importance degrees of website design parameters based on interactions and types of websites		Threshold value-average/determining weights using $R + C$
Yazdani-Chamzini et al. [28]	Analyze interdependence and dependencies and compute the global weights for evaluation indicators and propose a new hybrid model to select the strategy of investing in a private sector	AHP, fuzzy TOPSIS	Threshold value-experts/weights-$R + C$

Note. Backpropagation neural network: BPNN; balanced scorecard: BSC; building information modeling: BIM; cluster analysis: CA1; conjoint analysis: CA2; corporate social responsibility: CSR; customer perceived value: CPV; data envelopment analysis: DEA; decomposed theory of planned behavior: DTPB; dominance-based rough set approach: DRSA; electric vehicle: EV; enhanced driving force-pressure-state-impact-response: eDPSIR; enterprise resource planning: ERP; end-of-life: EOL; factor analysis: FA; failure mode and effect analysis: FMEA; fuzzy cognitive map: FCM; fuzzy inference system: FIS; formal concept analysis: FCA; gap analysis: GA; grey complex proportional assessment: COPRAS-G; grey relational analysis: GRA; houses of quality: HoQ; importance-performance analysis: IPA; importance-performance and gap analysis: IPGA; importance-satisfaction analysis: ISA; information technology: IT; interpretive structural modeling: ISM; integrated circuit: IC; key performance indicator: KPI; maximal entropy ordered weighted averaging: ME-OWA; multiple regression analysis: MRA; ordered weighted geometric averaging: OWGA; patent citation analysis: PCA; patent coclassification analysis: PCCA; relation map: RM; satisfied importance analysis: SIA; silicon intellectual property or Semiconductor-Intellectual-Property: SIP; social network analysis: SNA; structural equation modeling: SEM; technology acceptance model: TAM; theory of constraints: TOC; variable consistency DRSA: VC-DRSA.

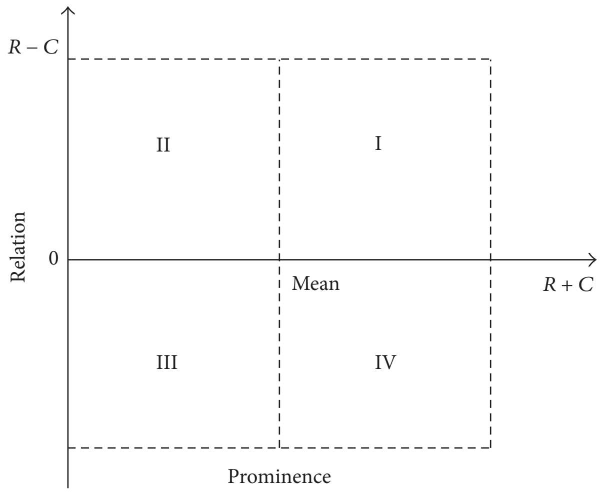

Figure 2: Four-quadrant IRM.

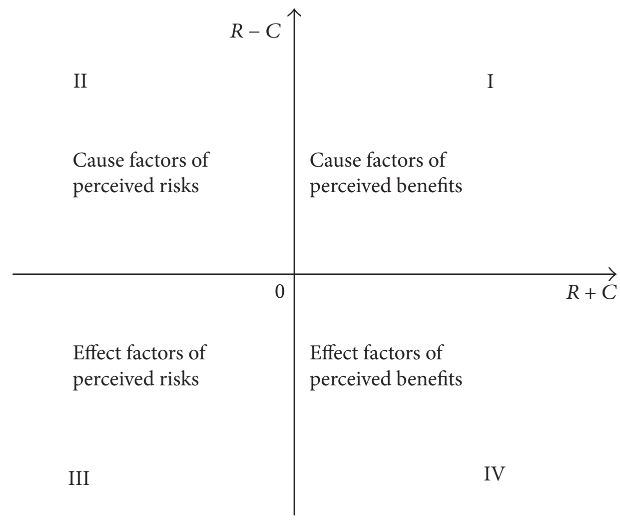

Figure 3: The PB-PR matrix.

Figure 2, by calculating the mean of $(R + C)$. The factors in quadrant I are identified as core factors or intertwined givers since they have high prominence and relation; the factors in quadrant II are identified as driving factors or autonomous givers because they have low prominence but high relation. The factors in quadrant III have low prominence and relation and are relatively disconnected from the system (called independent factors or autonomous receivers); the factors in quadrant IV have high prominence but low relation (called impact factors or intertwined receivers), which are impacted by other factors and cannot be directly improved. From Figure 2, decision makers can visually detect the complex causal relationships among factors and further spotlight valuable insights for decision making.

In addition, Wu et al. [23] developed a duo-theme DEMATEL to explore the decisive factors affecting the adoption Software as a Service (SaaS) in an organization. They treated the perceived benefits (PB) and perceived risks (PR) of adopting SaaS solutions as two distinct themes and developed a four-quadrant causal map, called PB-PR matrix, to facilitate decision making (see Figure 3). The primary difference between the duo-theme and the traditional DEMATEL is that the duo-theme DEMATEL combine two IRMs into a single PB-PR matrix by transforming "positive" $(R+C)$ value of each factor in PR into "negative" [24].

Step 5-1 (net influence matrix). After visualizing the complex causal relationships among factors using the IRM, Wang et al. [25, 26] further developed the net influence matrix $N = [\text{Net}_{ij}]_{n\times n}$ to evaluate the strength of influence of one factor on another, in which

$$\text{Net}_{ij} = t_{ij} - t_{ji}. \tag{8}$$

Step 6 (calculate the importance weights for criteria). In some studies, the classical DEMATEL technique was used to compute the weights of criteria. Normally, the criteria weights are determined based on the prominence $(R + C)$ through a normalization procedure as follows [27, 28]:

$$w_i = \frac{r_i + c_i}{\sum_{i=1}^{n} r_i + c_i}, \quad i = 1, 2, \ldots, n. \tag{9}$$

To correct for structural relations among criteria, Khazai et al. [29] proposed using the degree of dispatching, r_i, to calculate the dependency weights of criteria:

$$w_i^d = 1 - \frac{r_i - r_{\min}}{r_{\max} - r_{\min}}, \tag{10}$$

where $r_{\min} = n(\min_{i,j} t_{ij})$ and $r_{\max} = n(\max_{i,j} t_{ij})$.

Then, the overall weight of each criterion w_i is derived by

$$w_i = \frac{w_i^o}{\sum_{i=1}^{n} w_i^o}, \quad i = 1, 2, \ldots, n, \qquad w_i^o = w_i^{\text{im}} \times w_i^d, \tag{11}$$

where w_i^{im} is the importance weight of the ith criterion assigned by a group of experts.

3.1.2. Comparison with Other MCDM Methods. In the literature, a lot of effective MCDM methods were developed for dealing with group decision making problems [30–32]. In this part, the DEMATEL technique is compared with some other MCDM methods to show its advantages and disadvantages. We choose the most commonly used methods in MCDM, that is, analytic hierarchical process (AHP), grey relational analysis (GRA), technique for order performance by similarity to ideal solution (TOPSIS), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), and ELECTRE (ELimination Et Choix Traduisant la REalité), to compare the procedural basis of these MCDM methods.

In the AHP, a hierarchy considers the distribution of a goal among the elements being compared and judges which element has a greater influence on that goal [33, 34]. The GRA is an impact evaluation model that measures the degree of similarity or difference between two sequences based on relation grade [35]. The VIKOR method introduces the ranking index based on the particular measure of "closeness" to the ideal solution by using linear normalization [36]. The basic principle of the TOPSIS is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution [37]. The ELECTRE is a prominent outranking MCDM technique, which selects the best action from a proposed set of ones based on multiattribute utility theory [38]. Compared with these MCDM methods, the DEMATEL technique has the following advantages: (1) It effectively analyzes the mutual influences (both direct and indirect effects) among different factors and understands the complicated cause and effect relationships in the decision making problem. (2) It is able to visualize the interrelationships between factors via an IRM and enable the decision maker to clearly understand which factors have mutual influences on one another. (3) The DEMATEL can be used not only to determine the ranking of alternatives, but also to find out critical evaluation criteria and measure the weights of evaluation criteria. Although the AHP can be applied to rank alternatives and determine criteria weights, it assumes that the criteria are independent and fails to consider their interactions and dependencies. The ANP, an advanced version of the AHP, can deal with the dependence and feedback between criteria; but as indicated in [39–41], the assumption of equal weight for each cluster to obtain a weighted supermatrix in the ANP is not reasonable in practical situations.

On the other hand, in comparison to other MCDM methods, the possible disadvantages of the DEMATEL technique may be the following: (1) It determines the ranking of alternatives based on interdependent relationships among them; but other criteria are not incorporated in the decision making problem. (2) The relative weights of experts are not considered in aggregating personal judgments of experts into group assessments. (3) It cannot take into account the aspiration level of alternatives as in the GRA and VIKOR methods or obtain partial ranking orders of alternatives as in the ELECTRE approach. Therefore, the DEMATEL has been integrated with other MCDM methods to combine their desired properties in the literature. Next, we will discuss the situations in which it is more appropriate to use the DEMATEL method before some other methods.

3.1.3. Combination with Other Methods. Analyzing the data contained in Table 1, we can observe that the crisp DEMATEL has been combined with a variety of other methods or tools to solve the management decision problems effectively, and the methods most frequently integrated with the DEMATEL include AHP, balanced scorecard (BSC), TOPSIS, and quality function deployment (QFD). Generally, the classical DEMATEL are applied to the following circumstances in combination with other methods. First, it can be used to identify the interdependency among dimensions or perspectives. For example, the DEMATEL was applied to determine the interrelationships between four BSC perspectives [16] and to unveil the implicit interrelationships of customer requirements [210]. Second, it can be used to calculate the weights of evaluation criteria. For instance, the DEMATEL was employed to resolve criteria interdependency relationship weights and then the TOPSIS is utilized to evaluate the service quality of hot spring hotels [122]. Third, it can be used to determine critical factors or criteria via analyzing their dependent relations. For example, the DEMATEL method was applied first to select the most important sustainable criteria, and fuzzy AHP is constructed next to rank end-of-life vehicle management alternatives [108].

3.2. Fuzzy DEMATEL. In the original DEMATEL, the relationships of decision factors are assessed by crisp values so as to establish a structural model. However, in many real-world applications, human judgments are often unclear and exact numerical values are inadequate to estimate the vague interdependency relationships between criteria. Hence, the concept of fuzzy sets [214] has been applied to the DEMATEL method by many researchers. The fuzzy DEMATEL papers identified in this literature survey are summarized in Table 2 for the convenience of reading and understanding. This table also gives the classification of such papers based on different purposes of using the fuzzy DEMATEL. Generally, two types of fuzzy DEMATEL model have been put forward in the literature, that is, fuzzy logic and DEMATEL and fuzzy-based DEMATEL, which will be outlined briefly in the following.

3.2.1. Fuzzy Logic and DEMATEL. In this model, fuzzy logic and DEMATEL are combined in a decision model but implemented independently. This model first employs fuzzy sets to handle the experts' vague judgments and assessments on impact levels between factors and converts fuzzy numbers into crisp values for the group direct-influence matrix Z and then performs the classical DEMATEL procedure. Based on the basic definitions and operations of fuzzy sets, the following fuzzy logic and DEMATEL methodology was developed [130–132].

Step 1. Evaluate the mutual influences between factors using fuzzy linguistic scale.

In this step, it is necessary to establish a fuzzy linguistic scale to assess the causal relationships among factors. In order to tackle the vagueness and imprecision in human assessments, the linguistic terms "*No*, *Very Low*, *Low*, *High*, *Very High*" expressed in triangular fuzzy numbers can be used for the linguistic variable "influence." As a result, the individual direct-influence fuzzy matrix $\widetilde{Z}_k = [\widetilde{z}_{ij}^k]_{n\times n}$ is acquired for each of the respondents $E = \{E_1, E_2, \ldots, E_l\}$, where $\widetilde{z}_{ij}^k = (z_{ij1}^k, z_{ij2}^k, z_{ij3}^k)$ is the fuzzy assessment of expert E_k regarding the influence degree between factors F_i and F_j.

Step 2. Aggregate the assessments of experts and set up the group direct-influence fuzzy matrix $\widetilde{Z}$.

After constructing the individual matrixes $\widetilde{Z}_k$ ($k = 1, 2, \ldots, l$), we can calculate the group direct-influence fuzzy matrix $\widetilde{Z} = [\widetilde{z}_{ij}]_{n\times n}$ via aggregating all the experts' judgments, where $\widetilde{z}_{ii}$ can be viewed as a triangular fuzzy number $(0, 0, 0)$ and $\widetilde{z}_{ij}$ is derived by

$$\begin{aligned}\widetilde{z}_{ij} &= \left(z_{ij1}, z_{ij2}, z_{ij3}\right) = \frac{1}{l}\sum_{k=1}^{l}\widetilde{z}_{ij}^k \\ &= \left(\frac{1}{l}\sum_{k=1}^{l} z_{ij1}^k, \frac{1}{l}\sum_{k=1}^{l} z_{ij2}^k, \frac{1}{l}\sum_{k=1}^{l} z_{ij3}^k\right).\end{aligned} \quad (12)$$

Table 2: Various applications of fuzzy DEMATEL.

Papers	Categories	Research purposes	Combinations	Remarks
		Fuzzy logic and DEMATEL		
Kuo [125]	Interrelationships	Construct a suitable evaluation structure between criteria and propose a hybrid method for optimal location selection for an international distribution center	AHP/ANP, fuzzy TOPSIS, fuzzy measure	Defuzzification-CFCS/threshold value-average
Altuntas et al. [126]	Interrelationships	Find the closeness ratings between the facilities and propose a fuzzy approach for facility layout problem		Defuzzification-CFCS
Altuntas and Yilmaz [127]	Interrelationships Key factors/criteria	Identify the cause and effect factors of marketing resources and prioritize them for small- and medium-sized enterprises		Defuzzification-CFCS/threshold value-average
Kabak et al. [128]	Interrelationships Key factors/criteria	Determine critical success factors shaping the competitiveness level of the iron and steel industry in Turkey		Defuzzification-CFCS
Luthra et al. [129]	Interrelationships Key factors/criteria	Evaluate the enablers in solar power developments in in India's current scenario		Defuzzification-bisection of area
Wu and Lee [130]	Interrelationships Key factors/criteria	Propose a method to segment required competencies for promoting the competency development of global managers		Defuzzification-CFCS
Liou et al. [131]	Interrelationships Key factors/criteria	Map out the structural relations and identify key factors and develop a method for building an effective safety management system for airlines		Defuzzification-COA/threshold value-experts
Tseng [132]	Interrelationships Key factors/criteria	Integrate hotel service quality perceptions into a cause-effect model for assessing characteristics criteria of service quality measurement		Defuzzification-CFCS/inner dependence matrix
Tseng and Lin [133]	Interrelationships Key factors/criteria	Handle relations between cause and effect of criteria and develop a cause and effect model of municipal solid waste management		Defuzzification-CFCS/inner dependence matrix
Chang et al. [134]	Interrelationships Key factors/criteria	Evaluate supplier performance to find influential criteria in selecting suppliers		Defuzzification-CFCS
Chang and Cheng [135]	Interrelationships Key factors/criteria	Analyze the relation between failure modes and causes of failure and propose an approach to rank the risk of failures	Fuzzy OWA	Defuzzification-maximum degree of membership
Zhou et al. [136]	Interrelationships Key factors/criteria	Analyze causal relationships and identify key success factors for improving the overall emergency management		Defuzzification-CFCS
Tseng et al. [137]	Interrelationships Key factors/criteria	Handle the intertwining within a set of criteria and provide an integrated service quality expectation model for improving hot spring management		Inner dependence matrix

Table 2: Continued.

Papers	Categories	Research purposes	Combinations	Remarks
Tseng [138]	Interrelationships Key factors/criteria	Handle the inner dependence within decision criteria of EKMC and develop a model for evaluating the firm EKMC capacity		Defuzzification-CFCS/inner dependence matrix
Wu [139]	Interrelationships Key factors/criteria	Segment the critical factors for successful knowledge management implementations		Defuzzification-CFCS
Lin [140]	Interrelationships Key factors/criteria	Examine the cause and effect relationships among criteria and form a structural model to evaluate green supply chain management practices		Defuzzification-CFCS/inner dependence matrix
Patil and Kant [141]	Interrelationships Key factors/criteria	Identify critical success factors of knowledge management adoption in supply chain		Defuzzification-graded mean
Rouhani et al. [142]	Interrelationships Key factors/criteria	Evaluate and assess the critical factors in ERP project implementation	Fuzzy AHP	Defuzzification-CFCS
Wu et al. [143]	Interrelationships Key factors/criteria	Identify critical factors influencing the use of additives by food enterprises in China		Defuzzification-CFCS/threshold value-quartile
Zhou et al. [144]	Interrelationships Key factors/criteria	Measure the relationships among different factors and develop a root cause degree procedure for measuring intersection safety factors		Defuzzification-CFCS
Dou et al. [145]	Interrelationships Key factors/criteria	Examine the cause-effect interrelationships among ESDPs and proposes a model for focal companies to evaluate ESDPs	Fuzzy scoring method	Defuzzification-CFCS
Govindan et al. [146]	Interrelationships Key factors/criteria	Evaluate the drivers of corporate social responsibility implementation in the mining industry		Defuzzification-centroid method
Routroy and Sunil Kumar [147]	Interrelationships Key factors/criteria	Identify and establish relationship among various supplier development program enablers in a specific manufacturing environment		Defuzzification-CFCS/threshold value-average
Tyagi et al. [148]	Interrelationships Key factors/criteria	Assess critical enablers for flexible supply chain performance measurement system		Defuzzification-CFCS/threshold value-average
Wu et al. [149]	Interrelationships Key factors/criteria	Identify interactions among these criteria and explore decisive factors in green supply chain practices		Defuzzification-CFCS/inner dependence matrix

Table 2: Continued.

Papers	Categories	Research purposes	Combinations	Remarks
Sangaiah et al. [150]	Interrelationships Key factors/criteria Criteria weights	Evaluate GSD project outcome factors and find the significance of criteria in organizational behavior research phenomenon	TOPSIS	Defuzzification-CFCS/weights-vector length
Malviya and Kant [151]	Interrelationships Criteria weights	Predict and measure the success possibility of green supply chain management implementation		Defuzzification-CFCS/weights-$R + C$
Patil and Kant [152]	Interrelationships Criteria weights	Evaluate weighting of criteria and propose a prediction framework for knowledge management adoption in supply chain		Defuzzification-CFCS/weights-$R + C$
Sangaiah et al. [153]	Interrelationships Criteria weights	Present an integrated framework to evaluate knowledge transfer effectiveness with reference to GSD project outcome	TOPSIS, ELECTRE	Defuzzification-CFCS/weights-$R + C$
Bakeshlou et al. [154]	Interrelationships Criteria weights	Understand the interrelation among criteria and propose a hybrid MODM algorithm for green supplier selection	Fuzzy ANP, fuzzy MOLP	Defuzzification-CFCS/weights-fuzzy ANP
		Fuzzy-based DEMATEL		
Jassbi et al. [155]	Interrelationships	Capture the causal relationships between strategic objectives for a strategy map	BSC	Defuzzification-COG
Lee et al. [156]	Interrelationships	Reanalyze and explain the causal relationship and level of mutual effect between variables in TAM		Defuzzification-CFCS(T)/threshold value
Valmohammadi and Sofiyabadi [157]	Interrelationships	Analyze the causes and effects relations of strategy map and develop a strategy map for an automotive industry	BSC	Defuzzification-CFCS2/normalization and aggregation
Younesi and Roghanian [158]	Interrelationships	Assume the interdependence of customer attributes and propose a framework for sustainable product design	QFD, fuzzy ANP	Defuzzification-centroid method/threshold value-fuzzy MMDE

TABLE 2: Continued.

Papers	Categories	Research purposes	Combinations	Remarks
Lin and Wu [159]	Interrelationships Key factors/criteria	Propose a causal analytical method for group decision making under fuzzy environment and applied it for R&D project selection		Defuzzification-CFCS2/normalization and aggregation
Fekri et al. [160]	Interrelationships Key factors/criteria	Identify the cause and effect groups of critical success factors of agile new product development process	Explanatory factor analysis	Defuzzification-CFCS2/normalization and aggregation
Jeng and Tzeng [161]	Interrelationships Key factors/criteria	Explore the causal relationship between UTAUT variables and examine social influence on the use of clinical decision support system		Defuzzification-CFCS (T)/threshold value-experts
Chou et al. [162]	Interrelationships Key factors/criteria	Establish contextual relationships among criteria and evaluate the criteria for human resource for science and technology	Fuzzy AHP	Defuzzification-CFCS2/normalization and aggregation
Afsharkazemi et al. [163]	Interrelationships Key factors/criteria	Measure direct and indirect relationships between factors and identify key factors affecting the hospital performance		Defuzzification-centroid method/normalization and aggregation
Ren and Sovacool [164]	Interrelationships Key factors/criteria	Identify cause-effect relationships among energy security metrics, to determine the most salient and meaningful dimensions and energy security strategies		Defuzzification-CFCS2
Akyuz and Celik [165]	Interrelationships Key factors/criteria	Evaluate critical operational hazards during gas freeing process in crude oil tankers		Defuzzification-COA
Tsao and Wu [166]	Interrelationships Key factors/criteria	Evaluate the cause-effect relationship of complex drilling problems for compound special-core drilling composite materials		Defuzzification-CFCS2/normalization and aggregation
Ho et al. [167]	Interrelationships Key factors/criteria	Analyze the cause-effect relationship and the mutual influence of information security control items and identify core control items for information security management and improvement strategies		Defuzzification-CFCS2/threshold value
Jeng [168]	Interrelationships Key factors/criteria	Probe the relationships among key dimensions in supply chain collaboration to enable better strategic development of manufacturing firms		Defuzzification-CFCS (T)
Liu et al. [169]	Interrelationships Key factors/criteria	Analyze the relations between failure modes and causes of failure and propose a risk assessment methodology to rank the risk of failures	FWA	Defuzzification-graded mean
Panaihfar et al. [170]	Interrelationships Key factors/criteria	Explore the key factors in retailer selection for collaborative planning, forecasting, and replenishment and the relationships between these factors		Defuzzification-COA/threshold value-average of positive $R - C$
Hsu et al. [171]	Interrelationships Criteria weights Key factors/criteria	Find the key factors in building the structure relations of an ideal customer's choice behavior and propose a framework for marketing strategic planning	Fuzzy ANP, fuzzy AHP	Threshold value-average

Table 2: Continued.

Papers	Categories	Research purposes	Combinations	Remarks
Cebi [172]	Interrelationships Criteria weights Key factors/criteria	Determine critical design characteristics of websites based on interactions among them and present an integrated methodology to evaluate the perceived design quality of shopping websites	Choquet integral	Defuzzification-centroid method/weights-$R+C$/threshold value
Gigović et al. [173]	Interrelationships Criteria weights	Evaluate land suitability for the development of ecotourism in the region of "Dunavski Ključ"		Weights-vector length
Jeong et al. [174]	Interrelationships Criteria weights	Identify rural housings' suitable sites in reservoir areas under (mass) tourism		Weights-vector length
Rahimdel and Bagherpour [175]	Interrelationships Criteria weights	Determine the importance degree of criteria for the haulage system selection for open pit mines	Fuzzy TOPSIS	
Dalalah et al. [176]	Interrelationships Criteria weights	Deal with the influential relationship between the evaluation criteria and propose a hybrid fuzzy model for supplier selection		Defuzzification/weights-vector length/normalization and aggregation
Hiete et al. [177]	Interrelationships Criteria weights	Analyze and correct for relations between variables in a composite indicator for disaster resilience		Dependency weights/threshold value-graphical method
Wang and Chen [178]	Interrelationships Criteria weights	Derive the priorities of technical attributes and develop a fuzzy MCDM based QFD to assist an enterprise for collaborative product design	QFD, LIP	Defuzzification-centroid method (T)
Wang [179]	Interrelationships Criteria weights	Recognize the causalities between marketing requirements and technical attributes and propose an approach to conduct vendor assessment for business-intelligence systems	QFD, fuzzy AHP	Defuzzification-COA (T)/weights-$\|R-C\|$
Baykasoğlu et al. [180]	Interrelationships Criteria weights	Evaluate the weights of the criteria and propose a model for solving truck selection problem of a land transportation company	Fuzzy TOPSIS	Defuzzification-signed distance method/weights-vector length

Table 2: Continued.

Papers	Categories	Research purposes	Combinations	Remarks
Wang and Wu [181]	Interrelationships Criteria weights	Identify the dependence among evaluation factors and propose a framework to evaluate programmable logic controller suppliers	Fuzzy AHP	Defuzzification-centroid method (T)
Fetanat and Khorasaninejad [182]	Interrelationships Criteria weights	Deal with the influences of criteria into each other and propose a hybrid MCDM approach for offshore wind farm site selection	Fuzzy ANP, fuzzy ELECTRE	Defuzzification-Yager ranking method (T)/inner dependence matrix
Hu et al. [183]	Interrelationships Criteria weights	Addresses the interdependence and feedback effects between criteria and develop a hybrid MCDM model to improve mobile commerce adoption	Fuzzy DANP, fuzzy VIKOR	Weights-fuzzy DANP/fuzzy IRM
Keskin [184]	Interrelationships Criteria weights	Analyze the interactions between criteria and determine their weights for supplier evaluation and selection	Fuzzy c-means algorithm	Defuzzification-signed distance method/weights-vector length
Pamučar and Ćirović [185]	Interrelationships Criteria weights	Obtain the weight coefficients of criteria and present a model for the selection of transport and handling resources in logistics centers	MABAC	Defuzzification-graded mean (T)/weights-vector length
Taşkin et al. [186]	Interrelationships Criteria weights	Determine the importance weights of evaluation criteria and propose a framework for evaluating the hospital service quality	Fuzzy ANP, VIKOR	Defuzzification-CFCS (T)/threshold value-experts/weights-fuzzy ANP

Note. DEMATEL-based analytic network process: DANP; fuzzy weighted average: FWA; environmental practices in knowledge management capability: EKMC; environmental supplier development program: ESDP; global software development: GSD; linear integer programming: LIP; multiattributive border approximation area comparison: MABAC; multiobjective decision making: MODM; unified theory of acceptance and use of technology: UTAUT.

Step 3. Transform the group fuzzy assessments into crisp values and form the group direct-influence matrix Z.

Using a defuzzification method, the group direct-influence fuzzy matrix $\widetilde{Z} = [\widetilde{z}_{ij}]_{n\times n}$ can be defuzzified as a group direct-influence matrix Z. Or according to the CFCS (converting fuzzy data into crisp scores) method [215], the fuzzy assessments of experts $\widetilde{Z}_k$ $(k = 1, 2, \ldots, l)$ on the pairwise relations between factors can be defuzzified and aggregated into crisp scores to construct the group direct-influence matrix Z [126, 130, 132, 134, 136, 137, 139, 142–144, 147–149, 152].

Step 4. Apply the classical DEMATEL approach to

(i) establish the normalized direct-influence matrix X,

(ii) construct the total-influence matrix T,

(iii) produce the IRM.

From the group direct-influence matrix Z, the normalized direct-influence matrix X can be arrived at by (2). Then, the total-influence matrix T is obtained through (4). Finally, an IRM can be constructed by using (5), with the horizontal axis $(R + C)$ and the vertical axis $(R - C)$.

3.2.2. Fuzzy-Based DEMATEL. In this extended model, fuzzy logic is first employed to deal with the vagueness and imprecision involved in the influence degree estimation, then the DEMATEL analysis is completed, and finally the resulting fuzzy numbers are converted into numerical values for making decisions. The analytical procedure of fuzzy-based DEMATEL model is described as follows [159, 171].

Step 1. Evaluate the relationships between factors using fuzzy linguistic scale.

Step 2. Establish the group direct-influence fuzzy matrix $\widetilde{Z} = [\widetilde{z}_{ij}]_{n\times n}$.

Step 3. Generate the normalized direct-influence fuzzy matrix $\widetilde{X}$ by

$$\widetilde{X} = \frac{\widetilde{Z}}{r}, \tag{13}$$

where

$$\widetilde{X} = \begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{x}_{n1} & \widetilde{x}_{n2} & \cdots & \widetilde{x}_{nn} \end{bmatrix}, \tag{14}$$

$$r = \max_{1\le i\le n} \left(\sum_{j=1}^{n} z_{ij3} \right). \tag{15}$$

At least one i is assumed such that $\sum_{j=1}^{n} z_{ij3} < r$. Note that, in some studies [157, 159, 160, 162, 166, 176], the individual direct-influence fuzzy matrixes $\widetilde{Z}_k$ $(k = 1, 2, \ldots, l)$ are normalized first and then aggregated via arithmetic mean to get the normalized direct-influence fuzzy matrix $\widetilde{X}$. In addition, formula (16) was utilized to normalize the group direct-influence fuzzy matrix $\widetilde{Z}$ in [156, 161, 168, 172, 178, 179, 181, 183].

$$r = \max_{i,j} \left[\max_{1\le i\le n} \left(\sum_{j=1}^{n} z_{ij3} \right), \max_{1\le j\le n} \left(\sum_{i=1}^{n} z_{ij3} \right) \right]. \tag{16}$$

Step 4. Obtain the total-influence fuzzy matrix $\widetilde{T} = [\widetilde{t}_{ij}]_{n\times n}$ by

$$\widetilde{T} = \lim_{h\to\infty} \left(\widetilde{X}^1 + \widetilde{X}^2 + \cdots + \widetilde{X}^h \right) = \widetilde{X} \left(1 - \widetilde{X} \right)^{-1}, \quad \text{when } \lim_{h\to\infty} \widetilde{X}^h = O. \tag{17}$$

Here $\widetilde{t}_{ij} = (t_{ij1}, t_{ij2}, t_{ij3})$ and

$$\begin{aligned} T_1 &= \left[t_{ij1} \right]_{n\times n} = X_1 \left(I - X_1 \right)^{-1}, \\ T_2 &= \left[t_{ij2} \right]_{n\times n} = X_2 \left(I - X_2 \right)^{-1}, \\ T_3 &= \left[t_{ij3} \right]_{n\times n} = X_3 \left(I - X_3 \right)^{-1}, \end{aligned} \tag{18}$$

in which $X_1 = [x_{ij1}]_{n\times n}$, $X_2 = [x_{ij2}]_{n\times n}$, $X_3 = [x_{ij3}]_{n\times n}$, and I is an identity matrix. The elements of triangular fuzzy numbers in the matrix $\widetilde{T}$ are divided into T_1, T_2, and T_3, and $T_1 \prec T_2 \prec T_3$, when $x_{ij1} < x_{ij2} < x_{ij3}$ for any $i, j \in \{1, 2, \ldots, n\}$.

Step 5. Produce the IRM.

Once the total-influence fuzzy matrix $\widetilde{T}$ is obtained, then $\widetilde{R}_i + \widetilde{C}_i$ and $\widetilde{R}_i - \widetilde{C}_i$ can be calculated easily in which $\widetilde{R}_i$ and $\widetilde{C}_i$ are the sum of rows and the sum of columns within the matrix $\widetilde{T}$, respectively. Next, the fuzzy numbers of $\widetilde{R}_i + \widetilde{C}_i$ and $\widetilde{R}_i - \widetilde{C}_i$ are converted into crisp numbers by using a defuzzification method. A causal diagram can be drawn like the classical DEMATEL by mapping the ordered pairs of $(\widetilde{R}_i + \widetilde{C}_i)^{\text{def}}$ and $(\widetilde{R}_i - \widetilde{C}_i)^{\text{def}}$.

In the above, the fuzzy numbers are not transformed until after calculating the prominence degree $\widetilde{R}_i + \widetilde{C}_i$ and the net effect $\widetilde{R}_i - \widetilde{C}_i$. But a defuzzification step was implemented in Step 4 by some researchers [161, 179, 181, 182] to defuzzify the total-influence fuzzy matrix $\widetilde{T}$ into the total-influence matrix T. The rest of the steps are the same as the original DEMETAL technique.

Generally, triangular fuzzy numbers were utilized in the fuzzy DEMETAL studies except [129, 177]. In [177], the authors developed an extension of fuzzy DEMATEL to trapezoidal membership functions to analyze the complex cause-effect relationships between variables in a composite indicator for disaster resilience. In [129], the authors employed a fuzzy DEMATEL methodology using trapezoidal fuzzy numbers for evaluating the enablers in solar power developments in India.

3.2.3. Observations and Findings

(1) Defuzzification Methods. In the fuzzy DEMATEL literature, a variety of defuzzification methods have been employed for the factor interrelation analysis. Considering that the defuzzification of fuzzy numbers is very vital for the DEMATEL methodologies combined with fuzzy logic, we here conduct a survey on the defuzzification algorithms used in the fuzzy DEMATEL studies.

The CFCS method suggested by Opricovic and Tzeng [215] is the most prevalently adopted defuzzification algorithm in the fuzzy logic and DEMATEL models. For the fuzzy influence assessment $\tilde{z}_{ij}^k = (z_{ij1}^k, z_{ij2}^k, z_{ij3}^k)$ given by expert E_k, the defuzzification procedure based on the CFCS is performed as follows [130, 136, 138, 215, 216].

Step 1. Normalization of the fuzzy numbers:

$$\overline{z}_{ij1}^k = \frac{z_{ij1}^k - \min z_{ij1}^k}{\max z_{ij3}^k - \min z_{ij1}^k}, \quad (19)$$

$$\overline{z}_{ij2}^k = \frac{z_{ij2}^k - \min z_{ij1}^k}{\max z_{ij3}^k - \min z_{ij1}^k}, \quad (20)$$

$$\overline{z}_{ij3}^k = \frac{z_{ij3}^k - \min z_{ij1}^k}{\max z_{ij3}^k - \min z_{ij1}^k}. \quad (21)$$

Step 2. Compute left and right normalized values:

$$lz_{ij}^k = \frac{\overline{z}_{ij2}^k}{1 + \overline{z}_{ij2}^k - \overline{z}_{ij1}^k}, \quad (22)$$

$$rz_{ij}^k = \frac{\overline{z}_{ij3}^k}{1 + \overline{z}_{ij3}^k - \overline{z}_{ij2}^k}. \quad (23)$$

Step 3. Compute total normalized crisp value:

$$tz_{ij}^k = \frac{lz_{ij}^k \left(1 - lz_{ij}^k\right) + rz_{ij}^k rz_{ij}^k}{1 - lz_{ij}^k + rz_{ij}^k}. \quad (24)$$

Step 4. Compute crisp values:

$$z_{ij}^k = \min z_{ij1}^k + tz_{ij}^k \left(\max z_{ij3}^k - \min z_{ij1}^k\right). \quad (25)$$

Then, the different judgments of l experts are integrated to construct the group direct-influence matrix Z by

$$z_{ij} = \frac{1}{l} \sum_{k=1}^{l} z_{ij}^k. \quad (26)$$

In the fuzzy-based DEMATEL methods, the following CFCS method was applied to calculate the prominence $(\widetilde{R}_i + \widetilde{C}_i)^{\text{def}}$ and the relation $(\widetilde{R}_i - \widetilde{C}_i)^{\text{def}}$ [159, 162, 164, 167]:

$$y_i = L + \Delta \times \frac{(m_i - L)(\Delta + u_i - m_i)^2 (R - l_i) + (u_i - L)^2 (\Delta + m_i - l_i)^2}{(\Delta + m_i - l_i)(\Delta + u_i - m_i)^2 (R - l_i) + (u_i - L)(\Delta + m_i - l_i)^2 (\Delta + u_i - m_i)}, \quad (27)$$

where y_i denotes the defuzzified value of the fuzzy number $\widetilde{y}_i = (l_i, m_i, u_i)$, $L = \min l_i$, $R = \max u_i$ and $\Delta = R - L$.

The centroid method (center-of-gravity (COG) or center of area (COA)) was used to determine the crisp values of fuzzy numbers in [131, 158, 165, 170, 179]. For the triangular fuzzy number $\widetilde{y} = (l, m, u)$, its crisp value can be found with the following equivalent relations:

$$y = l + \frac{(m - l) + (u - l)}{3}, \quad \text{or } y = \frac{l + m + u}{3}. \quad (28)$$

In [180, 184], the signed distance of a fuzzy number (called signed distance method or Yager ranking method in [182]) shown in (29) was used as its defuzzified value. Patil and Kant [141] defuzzified each fuzzy number into a crisp value by using the graded mean integration representation method as (30). In [176], the defuzzification of fuzzy numbers is carried out using (31) to compute the point that divides the area of a fuzzy set into two equal parts.

$$y = \frac{l + 2m + u}{4}, \quad (29)$$

$$y = \frac{l + 4m + u}{6}, \quad (30)$$

$$y = \begin{cases} u - \sqrt{\dfrac{(u - l)(u - m)}{2}}, & u - m > m - l, \\ \sqrt{\dfrac{(u - l)(u - m)}{2}} - l, & u - m < m - l, \\ m, & \text{otherwise}. \end{cases} \quad (31)$$

(2) Weighting Methods. As shown in Table 2, many studies have applied the fuzzy DEMETAL to determine the weights of criteria considering their hierarchies, and a variety of weighting methods have been suggested. In addition to those methods already mentioned in the classical DEMETAL studies, that is, those based $R + C$ and dependency weights, some new weighting methods have been developed.

The vector length method has been used in [150, 176, 180, 184], which sets the importance of criteria with the following formula:

$$\omega_i = \left[\left(\widetilde{R}_i^{\text{def}} + \widetilde{C}_i^{\text{def}}\right)^2 + \left(\widetilde{R}_i^{\text{def}} - \widetilde{C}_i^{\text{def}}\right)^2\right]^{1/2}. \quad (32)$$

Then the weight of any criterion can be normalized as follows:

$$w_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i}, \quad i = 1, 2, \ldots, n. \tag{33}$$

Wang [179] evaluated the importance weights of criteria by normalizing their absolute relation values:

$$w_i = \frac{|r_i - c_i|}{\sum_{i=1}^{n} |r_i - c_i|}, \quad i = 1, 2, \ldots, n. \tag{34}$$

Here $|r_i - c_i|$ represents a signed relation value for the jth criterion.

Besides, based on the interactions among criteria, fuzzy AHP was utilized by Wang and Wu [181] and Hsu et al. [171], fuzzy ANP was used by Taşkin et al. [186], Fetanat and Khorasaninejad [182], and Bakeshlou et al. [154], and fuzzy DEMATEL-based analytic network process (DANP) was employed by Hu et al. [183] to calculate relative weights of criteria.

3.3. Grey DEMATEL. Grey theory [35] is a mathematical theory proposed to cope with systems which lack information. It is an effective methodology to resolve uncertain and indeterminate problems and is superior in theoretical analysis of systems with discrete data and incomplete information. Hence, grey theory has been incorporated with the DEMATEL by some researchers for the evaluation of factor intertwined relations in real-life systems. To facilitate reading and comparison, the reviewed twelve grey DEMATEL studies are summarized in Table 3. All of them adopted grey DEMATEL methods for the identification of key factors through analyzing the interaffected relationships among them.

Similar to the fuzzy DEMATEL, there are mainly two types of grey DEMATEL methods, that is, the grey theory and DEMATEL and the grey-based DEMATEL. Fu et al. [187] first introduced the grey theory and DEMATEL methodology to investigate the importance of green supplier development programs at a telecommunications systems provider. The proposed method involves assessing interdependency relationships among factors by a grey linguistics scale, transforming grey numbers into single real numbers using a modified CFCS process, and eventually executing the classical DEMATEL steps to obtain an IRM with associated analysis. Later, the grey theory and DEMATEL method was applied by Dou and Sarkis [188] to evaluate the barriers of implementing China RoHS (the restriction of the use of hazardous substances in electrical and electronic equipment) regulations from a multiple stakeholder perspective, by Zhu et al. [189] to identify the supply chain-based barriers for truck-engine remanufacturing in China, by Rajesh and Ravi [190] to ascertain the major enablers of supply chain risk mitigation in electronic supply chains, by Shao et al. [191] to analyze the barriers between environmentally friendly products and consumers on the European automobile industry, by Govindan et al. [192] to develop important criteria for third-party logistics provider selection and evaluation, and by Xia et al. [193] to analyze the internal barriers for remanufacturers in the Chinese automotive sector.

Bai and Sarkis [194] argued that the data conversion process of the grey and DEMATEL method will cause a loss of original decision information, thus leading to unreasonable or misleading results in the final decision. Accordingly, they proposed a grey-based DEMATEL model to identify critical success factors (CFSs) in the successful implementation of business process management (BPM). In their integrated structural model, the authors evaluated various BPM implementation CSFs directly through the grey-based DEMATEL and did not "degrey" the grey numbers until after calculating the prominence and relation indexes. Liang et al. [195] also reported a grey-based DEMATEL for identifying the CFSs for promoting sustainable development of biofuel industry in China.

Additionally, Tseng [196] proposed a grey-fuzzy DEMATEL approach based on a grey possibility degree to deal with real estate agent service quality expectation ranking with uncertainty. Su et al. [197] developed a hierarchical grey DEMATEL methodology for improving sustainable supply chain management under hierarchical structure interrelationships and incomplete information. Ozcan and Tuysuz [197] elaborated upon a grey-based multicriteria performance evaluation model for retail stores by integrating DEMATEL and GRA methods.

It is worth noting that different from the threshold determination methods mentioned in the traditional DEMATEL part, the threshold value θ in the grey DEMATEL papers was usually yielded based on the mean (μ) and standard deviation (σ) of the values from the total-influence matrix T. For example, in [187, 191, 193, 194], the threshold is set up by computing the sum of the mean and standard deviation (μ+σ). Rajesh and Ravi [190] set the threshold value by adding 1.5 times the standard deviation to the mean ($\mu + 1.5\sigma$) and Zhu et al. [189] added two standard deviations to the mean ($\mu + 2\sigma$) to calculate the value of θ.

3.4. Other DEMATEL Methods. In previous sections, we have overviewed the DEMATEL for decision making under different contexts, that is, the original crisp DEMATEL, the fuzzy DEMATEL, and the grey DEMATEL. Recently, various approaches that combine other new uncertain theories with DEMATEL have been put forward to enhance its analysis capability and practicality. Table 4 shows those modifications identified in the literature and, in the sequence, a detailed literature analysis is given.

Jenab et al. [199] proposed an interval DEMATEL (i-DEMATEL) method for evaluating and implementing computer integrated manufacturing technologies that takes into account all decision parameters. Abdullah and Zulkifli [200] reported an interval type 2 fuzzy DEMATEL (IT2-fuzzy DEMATEL) and combined it with fuzzy AHP for human resource management, where interval type 2 trapezoidal fuzzy numbers were used to resolve the relationships among dimensions and criteria. Nikjoo and Saeedpoor [201] presented an intuitionistic fuzzy DEMATEL approach to determine the key components of strengths, weaknesses, opportunities, and threats (SWOT) matrix, and Govindan et al. [202] used the DEMATEL method with intuitionistic fuzzy sets (IFSs) to handle the important and causal relationships

Table 3: Applications of grey DEMATEL.

Papers	Research purposes	Extensions	Remarks
Fu et al. [187]	Evaluate green supplier development programs and their relationships to each other and importance for the organization	Grey theory and DEMATEL	Modified CFCS/threshold value-$\mu + \sigma$
Dou and Sarkis [188]	Evaluate the barriers of implementing China RoHS regulations from a multiple stakeholder perspective	Grey theory and DEMATEL	Modified CFCS/threshold value-μ/distance between respondents
Zhu et al. [189]	Examine the causal-effect relationships among the implementation barriers and identify supply chain-based barriers for truck-engine remanufacturing in China	Grey theory and DEMATEL	CFCS/threshold value-$\mu + 2\sigma$/distance between respondents
Rajesh and Ravi [190]	Find out cause/effect relationships and ascertain the major enablers of supply chain risk mitigation in electronic supply chains	Grey theory and DEMATEL	Modified CFCS/threshold value-$\mu + 1.5\sigma$
Shao et al. [191]	Visualize the prioritization and interrelationships of the barriers between environmentally friendly products and their consumers on the European automobile industry	Grey theory and DEMATEL	Modified CFCS/threshold value-$\mu + \sigma$
Govindan et al. [192]	Identify important criteria for third-party logistics provider selection	Grey theory and DEMATEL	Modified CFCS/inner dependence matrix
Xia et al. [193]	Analyze internal barriers for remanufacturers in the automotive sector and identify the causal internal barriers in the Chinese automotive sector	Grey theory and DEMATEL	Modified CFCS/threshold value-$\mu + \sigma$
Bai and Sarkis [194]	Evaluate business process management (BPM) critical success factors to aid project managers make proper BPM investment strategies	Grey DEMATEL	Threshold value-$\mu + \sigma$
Liang et al. [195]	Identify critical success factors for sustainable development of biofuel industry in China	Grey DEMATEL	
Tseng [196]	Resolve interdependency relationships among criteria and present a perception approach to deal with real estate agent service quality expectation ranking	Grey-fuzzy DEMATEL	Inner dependence matrix
Su et al. [197]	Identify aspects of and criteria for supplier prioritization and propose a hierarchical method for improving sustainable supply chain management	Hierarchical grey DEMATEL	
Ozcan and Tuysuz [198]	Determine the importance of performance indicators and propose a method for the performance evaluation of retail stores	Grey-based DEMATEL	Modified CFCS

Table 4: Applications of other DEMATEL.

Papers	Categories	Research purposes	Extensions	Remarks
Jenab et al. [199]	Interrelationships Key factors	Propose a systematic method for evaluating and selecting computer integrated manufacturing (CIM) technologies taking into account management objectives	Interval DEMATEL	Rank based on $R - C$
Abdullah and Zulkifli [200]	Interrelationships Key factors	Capture the complex relationships among dimensions and criteria and propose an integration method for human resources management	IT2-fuzzy DEMATEL, fuzzy AHP	Defuzzification-expected value (T)
Nikjoo and Saeedpoor [201]	Interrelationships Key factors	Deal with the causal relationships among factors and propose a methodology for prioritizing the components of SWOT matrix	IFS (ITFN) and DEMATEL	Defuzzification-expected value/inner dependence matrix
Govindan et al. [202]	Interrelationships Key factors	Handle the important and causal relationships between green supply chain management (GSCM) practices and find the main practices to improve environmental and economic performances	IFS (ITFN) and DEMATEL	Defuzzification-expected value/inner dependence matrix
Fan et al. [203]	Interrelationships Key factors	Examine the interrelationships among the risk factors of IT outsourcing and identify the importance together with the classification of risk factors	2-tuple and DEMATEL	
Liu et al. [204]	Interrelationships Criteria weight	Obtain the relative weights of criteria and propose a hybrid MCDM for evaluating health-care waste treatment technologies	2-tuple and DEMATEL, fuzzy MULTIMOORA	Criteria weights-vector length
Suo et al. [205]	Interrelationships Key factors	Deal with correlated factor analysis problems using uncertain linguistic terms and extend the classical DEMATEL method to an uncertain linguistic environment	Uncertain linguistic DEMATEL	Defuzzification-COG
Li et al. [206]	Interrelationships Key factors	Identify critical success factors in emergency management	Evidential DEMATEL (D-S theory and IFS)	
Chang and Cheng [207]	Interrelationships Key factors	Analyze the relationships between components of a system and outline a general algorithm for prioritization of failure modes in FMEA	IFS and DEMATEL	Defuzzification-centroid method/rank based on $R - C$
Chang [208]	Interrelationships Key factors	Analyze the relationships between components of a system and outline a general algorithm for prioritization of failure modes in FMEA	Soft set and DEMATEL	Rank based on $R - C$
Geng and Chu [209]	Interrelationships Criteria weights	Consider the mutual influence relationships among attributes and propose a new importance-performance analysis (IPA) approach for customer satisfaction evaluation	Vague DEMATEL, Kano model	Defuzzification-average
Wu et al. [210]	Interrelationships Criteria weights	Analyze the interrelationships among customer requirements and propose an integrated analytical model for quality function deployment (QFD)	Hesitant fuzzy DEMATEL	Criteria weights-vector length

between green practices and performances in green supply chain management. Fan et al. [203] developed an extended DEMATEL method using 2-tuple fuzzy linguistic representation model to identify risk factors of IT outsourcing, and Liu et al. [204] utilized a 2-tuple DEMATEL technique to compute the importance weights of criteria and proposed a hybrid MCDM model for evaluating health-care waste treatment technologies.

Suo et al. [205] presented an extension of DEMATEL method in an uncertain linguistic environment, which allows the judgments on the correlations between factors in the form of uncertain linguistic terms. Li et al. [206] proposed an evidential DEMATEL method for identifying CFSs in emergency management, in which the evaluations of influencing factors expressed in intuitionistic fuzzy numbers (IFNs) were transformed into basic probability assignments (BPAs) and Dempster-Shafer (D-S) theory was used to obtain the group assessment BPA matrix. Chang and Cheng [207] suggested an efficient algorithm which combines IFSs and the DEMATEL to evaluate the risk of failure modes and Chang [208] proposed a risk ranking model integrating soft set theory and the DEMATEL technique for the risk assessment in failure mode and effect analysis (FMEA). Geng and Chu [209] dealt with the uncertainty and vagueness of expert evaluations by using vague sets and presented a revised DEMATEL approach to capture the mutual influence relationships among quality attributes. Then, a new importance-performance analysis (IPA) method for customer satisfaction evaluation was proposed based on Kano model and vague DEMATEL. Wu et al. [210] presented an integrated analytical model for QFD, in which hesitant fuzzy DEMATEL was adopted to analyze the interrelationships among customer requirements and determine their weights.

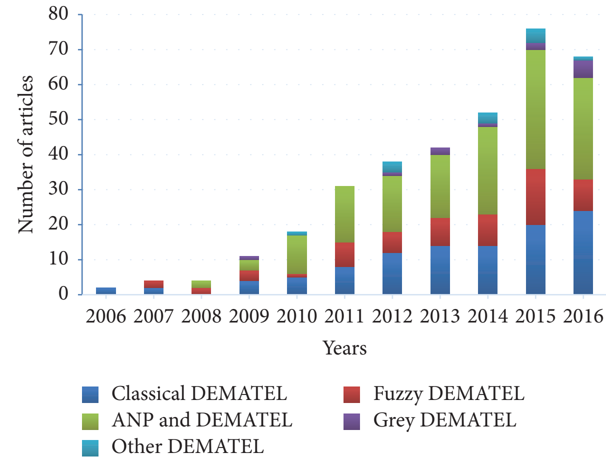

Figure 4: Distribution of articles according to the years.

Table 5: The top ten papers based on citation measures.

Papers	Total citation	Average citation
Tzeng et al. [10]	334	41.75
Wu and Lee [130]	224	28.00
Lin and Wu [159]	166	23.71
Wu [211]	162	23.14
Huang et al. [8]	131	16.38
Büyüközkan and Çifçi [212]	128	42.67
Tsai and Chou [213]	128	21.33
Seyed-Hosseini et al. [77]	128	14.22
Chiu et al. [49]	128	14.22
Chang et al. [134]	83	20.75

4. Bibliometric Analysis

Based on the collected papers on the DEMATEL, a bibliometric analysis is conducted in this section regarding quantity of articles published per year, application areas of DEMATEL, and the highly cited papers. The intention of this bibliometric analysis is to find out current research trends, distribution of the articles in different categories, and interactions with other fields, which provide valuable insights for researchers and practitioners working in this field. First, from Figure 4, one can observe that the number of publications on DEMATEL has increased considerably, especially after the year 2009. It can be expected that the studies of utilizing the DEMATEL and its variants will continue to grow at an increased pace in the coming decade. Figure 4 also shows the trend in the number of publications in each category. It can be found that the classical and the fuzzy DEMATEL methods are mostly used for decision making in the earlier literature. It was only after the year 2010 when the focus shifted to employing the combination of ANP and DEMATEL. However, the usage of the classical and the fuzzy DEMATEL methods has continued to grow until more recently when some papers began to deal with the grey and other DEMATEL applications. Normally, if the relationships of systems are given by crisp values in establishing a structural model, the classical DEMATEL can be used for evaluating problems and decision making [217]. For the cases that the human judgments about preferences are unclear and hard to estimate by exact numerical values, the fuzzy DEMATEL is necessary for making better decisions in fuzzy environments. The grey DEMATEL can be applied to the systems with limited data and incomplete information, which may exhibit random uncertainty.

From Figure 5, we can see that the DEMATEL and its various improvements have been widely used in a lot of areas, practically in computer science (40.6%), engineering (35.7%), business and managements (26.4%), decision sciences (17.7%), and social sciences (15.5%).

In Table 5, the top ten papers are given by analyzing the total citation and average citation of each publication. “Total citation” refers to the number of Scopus citations for a paper until 2016, and “average citation” or called “citation per year” is equal to the total citation divided by the number of years from publication. It can be seen that the most influenced papers in this filed are Tzeng et al. [10], Wu and Lee [130], Lin and Wu [159], Wu [211], Huang et al. [8], and Büyüközkan and Çifçi [212]. Note that the ranking of articles based upon the total citation does not necessarily match the average citation ranking. Besides, it can be observed that all the highly cited studies are at least five years old except Büyüközkan

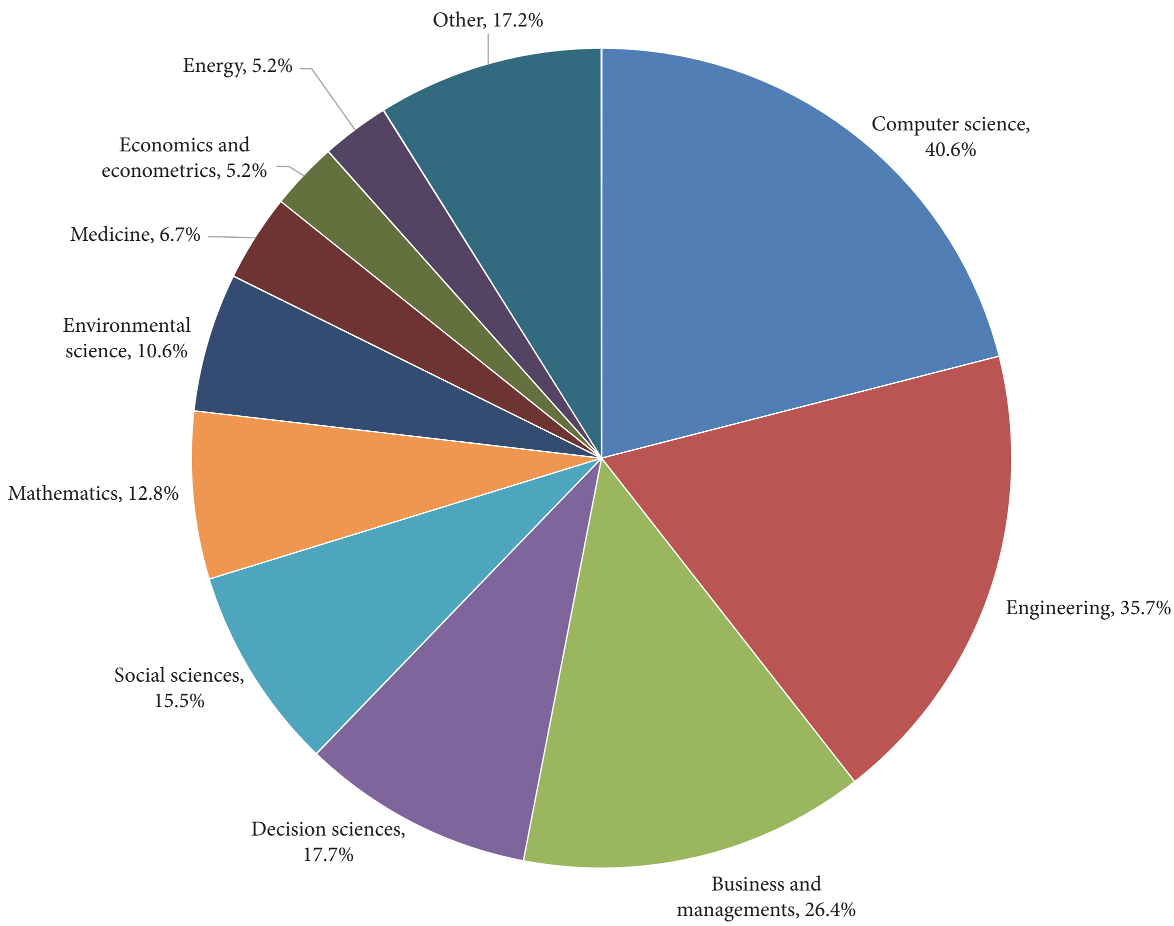

Figure 5: Distribution of articles according to application areas.

and Çifçi [212]. This is because sufficient time is usually needed for an influential paper to establish citations.

5. Conclusions and Suggestions for Future Work

In recent decade, the DEMATEL technique has attracted a lot of attention from both practitioners and researchers and has been used in a wide range of areas due to its ability to handle complex relationships between components of a system. In this paper, a representative and comprehensive review on the DEMATEL methods and applications from 2006 to 2016 was provided. According to the distinct forms of the DEMATEL used in the selected publications, five categories are identified and carefully investigated along with their main steps and characteristics. This review uncovers the current state of the research on this area based on statistical analysis results of the DEMATEL literature. It can be expected that the number of approaches and applications of the DEMATEL will continue to grow in the future due to its distinguished power and the increasing complexity of decision making problems.

Through the detailed review regarding the DEMATEL methodologies, the following possible future research directions for both theory and applications are suggested. First, to represent uncertainty and vagueness within the decision making process, the original DEMATEL was mainly combined with fuzzy sets and grey theory and only a few studies applied other uncertain theories, such as interval type 2 fuzzy sets, IFSs, 2-tuples and uncertain linguistic terms, to improve the DEMATEL recently. In the future, investigating the combination of DEMATEL with more advanced uncertain theories, such as hesitant fuzzy linguistic term sets and cloud model theory, for better decisions in uncertainty would be interesting. Second, the relative weights of decision makers are assumed to be equally important in computing the group direct-influence matrix Z. However, in practical situations, decision makers usually come from different specialty fields and each expert has unique characteristics with regard to knowledge, skills, experience, and personality, which implies that different expert weights should be assigned to reflect their influences on final analysis results. Moreover, in the interrelationship evaluation process, some decision makers may assign unduly high or unduly low preference values to their "preferred" or "repugnant" factors. Thus, in the future, advanced DEMATEL methods should be developed to relieve the influence of unfair arguments on the decision results. Third, proposing more objective and effective methods is required to set the crucial parameters in DEMATEL such as threshold value θ and criteria weights in further research. For example, although different methods have been suggested to determine the value of θ in current DEMATEL studies, these methods are subjective and time-consuming [218].

From the perspective of applications, our study also has several implications for further research. First, the literature review shows that a series of modified DEMATEL approaches have been developed, but no or few studies have been done to compare between the methods in the same or different groups. So, one recommendation for future research is the evaluation and comparison of the advantages and drawbacks of different DEMATEL methods in order to aid practitioners to select the suitable one for the problem to be solved. Second, to analyze the complicated interrelations between factors accurately, many computations are involved in the extended DEMATEL models, which limit their applications. Thus, a software tool should be developed in the future to facilitate the implementation of the DEMATEL technique. Finally, future research could apply the DEMATEL methodology and its variants to other situations and broader fields that are not considered in the previous studies.

Conflicts of Interest

The authors declare no conflicts of interest.

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