An Integrated DEMATEL with Bipolar neutrsophic Dombi-based Heronian Mean Operator and Its Applications in Decision-making Problem

Siti Nurhidayah Yaacob[1], Hazwani Hashim[2*], Nor Hashimah Sulaiman[3], Noor Azzah Awang[4], Ashraf Al-Quran[5], Lazim Abdullah[6]

[1,4] School of Mathematical Sciences, College of Computing, Informatics and Mathematics, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia.
[2] School of Mathematical Sciences, College of Computing, Informatics and Mathematics, Universiti Teknologi MARA (UiTM), Kelantan Branch, 18500 Machang, Kelantan, Malaysia.
[3] Centre of Foundation Studies, Universiti Teknologi MARA (UiTM), Selangor Branch, Dengkil Campus, 43800 Dengkil, Selangor, Malaysia.
[5] Department of Mathematics and Statistics,College of Science, King Faisal University, Al-Ahsa, 31982, Saudi Arabia.
[6] Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu (UMT), Kuala Nerus, 21030, Malaysia.
Emails: sitinurhidayahyaacob@gmail.com; hazwanihashim@uitm.edu.my; norhashimah@uitm.edu.my; azzahawang@uitm.edu.my; aalquran@kfu.edu.sa; lazim_m@umt.edu.my

Abstract

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach is commonly used in examining and illustrating the relationship between different factors in a complex system. This paper proposes a novel approach that integrates the Bipolar neutrosophic Dombi-based IGWHM operator into the DEMATEL method, in which the criteria are analyzed by means of the cause-and-effect relationship diagram. The current studies on the classical DEMATEL approach have some limitations on the aggregation process, particularly in capturing the interrelationship of individual arguments by assessing their impact on each other within a complex system. To enhance the aggregation of complex information in the decision-making framework, the Bipolar neutrosophic Dombi-based Improved Generalized Weighted Heronian mean (IGWHM) operators are employed. The applicability and effectiveness of the proposed approach are demonstrated when solving a selection of transport service providers. The ability of the method to highlight the intricate interdependencies and ranking criteria based on their importance. The sensitivity of the developed approach is observed with variations in the involved parameter. Moreover, a comparative analysis is made with other methods to demonstrate its validity.

Keywords: Decision-making; Bipolar Neutrosophic Set; Improved Generalized Weighted Heronian Mean; DEMATEL.

1. Introduction

Decision-making problems are fundamental element to various fields, including engineering [1], healthcare [2], the environmental sciences [3], management [4], automobile [5], and many more. It involves evaluating alternatives and selecting the best course of action based on several factors or criteria. Understanding the complex relationships and interdependencies between these factors is essential for making informed decisions. Decision-making problems require decision-makers (DM) to consider multiple factors, weight different priorities, and make informed choices based on available information and resources. Effective decision-making is crucial for the success and progress of

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

organizations. One method proposed by Battelle Geneva Institute that helps in analyzing these relationships is the Decision Making Trial and Evaluation Laboratory (DEMATEL) technique [6].

The DEMATEL technique is a powerful tool that provides a structural framework for understanding the causal relationships among decision-making factors. By using DEMATEL, DMs can identify each factor's direct and indirect influences on the overall decision outcome. By examining these relationships, decision-makers can gain valuable insights and make more informed and effective decisions. Also, this technique allows for the visualization and analysis of the cause-effect relationships among the elements in a complex system [7]. DEMATEL provides a structured framework for decision-making by identifying key factors, evaluating their interdependencies, and determining their relative importance. The use of DEMATEL in decision-making problems has gained popularity due to its ability to provide a comprehensive analysis and understanding of the relationships between different criteria and variables involved in the decision-making process.

By incorporating fuzziness into the decision-making process, fuzzy DEMATEL (F-DEMATEL) allows decision-makers to account for uncertainties and vagueness in the data, thus improving the accuracy and robustness of the decision-making process. The field of fuzzy logic was established by Zadeh [8] in order to investigate how humans make decisions in the context of ambiguity and uncertainty. In the literature, Mahmoudi et al. [9] assessed heart failure self-care elements under uncertain circumstances using the DEMATEL method. Also, Suzan and Yavuzer [10] used the F-DEMATEL method to assess the most common diseases in internal medicine outpatient clinics. Next, Ghadami et al. [11] studied F-DEMATEL to rank and weight accreditation categories, subcategories, and hospital standards. According to Kamalov et al. [12], the same method was used to identify causal factors for security issues. Seker and Zavadskas [13] suggested an F-DEMATEL technique to assess occupational risks at construction sites. In the case of COVID-19, Ocompo and Yamagishi [14] use the intuitionistic fuzzy DEMATEL method to analyze the escalating pandemic in the Philippines.

Later, DEMATEL was expanded in a neutrosophic environment. This integration allows decision-makers to handle uncertainties, imprecisions, and indeterminacies more effectively, providing a more flexible framework for decision analysis. The neutrosophic DEMATEL method considers the causal relationships between variables. It incorporates the concepts of truthiness, indeterminacy, and falsity proposed by Smarandache [15] to address the uncertainties and vagueness in decision-making. The study of this method has been applied in many fields including but not limited to transportation [16], supply chain management [17], project selection [18]. The following year, Kilic et al. [19] developed an approach for evaluating leanness, and Mamites et al. [20] investigated factors affecting university teaching quality using the DEMATEL method under neutrosophic sets (NS).

The DEMATEL has been extended to enhance decision-making in diverse environments, considering the presence of uncertain information in real-life situations. As an extension of the NS proposed by Deli et al. [21], the Bipolar neutrosophic set (BNS) considers both the positive and negative sides of the problem. The BNS has been applied to solving some decision-making problems, including location selection [22], agriculture [23], car selection [24], and professional selection [25]. Recently, the combination of BNSs with the DEMATEL method has been explored to provide a robust and reliable approach to decision-making processes. It enables decision-makers to handle uncertainties and complexities inherent in real-world problems, leading to more accurate and informed decisions. The studies of NS-DEMATEL have been successful in various domains, including coastal erosion problem [26], urban sustainability [27], sustainable energy selection [28], smart supply chain [29], and green supply chain [30].

The aggregation operators (AOs) are one of important component in DEMATEL method. AOs are important because they combine the evaluations of all decision makers into a single collective evaluation before proceeding to the next steps. AOs can be used to summarize and synthesize the criteria information, allowing decision-makers to make informed choices based on their priorities and preferences. There are various AOs available in the literature with different functions such as Choquet integral [31], power average [32], ordered weighted geometric [33], Bonferroni mean (BM) [34], Heronian mean (HM) [35], and harmonic mean [36]. Another, well known AOs that shared common function namely BM and HM operators. These operators shared a common function, namely the consideration of the interrelationship between two input arguments C_i and C_j. However, the BM operator's structure principle $(i \neq j)$ can result in redundant information due to repetitive interrelationship computation, reducing the efficiency of information fusion. Meanwhile, the structure

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

principle of the HM operator $(i = j)$ allows for the consideration of the interrelationship between two input arguments without involving redundant computations. HM has been extended to handle crisp numbers, which is called improved generalized weighted HM (IGWHM) by Liu [37]. Hence, we use IGWHM operators in order to handle uncertain, imprecise, and indeterminate information that exist in real life problems. However, research on HM operators is limited to the algebraic product and sum only, as indicated by studies conducted by [38] – [42]. Dombi [43] proposed Dombi operation called Dombi t-norm (TN) and Dombi t-conorm (TCN). Numerous operational rules based on different set domains are generated by Dombi operations. In this study, Bipolar neutrosophic Dombi-based IGWHM operator is used in aggregating process.

Based on published research, the DEMATEL method aggregated data using the classical arithmetic mean (AM) and geometric mean (GM), as in the study by [20], [28], [44] and [45]. However, the AM and GM cannot consider the interrelationship of input arguments. The interrelationship is important in aggregating process as it captures the correlations among aggregated arguments. The Heronian mean (HM) is one of the operators that can take into account the interrelationship of input arguments. Meanwhile, Dombi operator is employed in HM because of the advantages of its flexibility of operations corresponding to changeable parameter. In order to solve the interrelationship of input argument in aggregating process of the DEMATEL method, we integrated the Bipolar neutrosophic Dombi-based IGWHM with DEMATEL method.

This paper can be categorized as follows: Section 2 illustrates the definition of a Bipolar neutrosophic set (BNS), denutrosophication of a BNS, Heronian mean aggregation operators, and a Bipolar neutrosophic Dombi-based improved generalized weighted Heronian mean operator (BND-IGWHM). Section 3 presents the methodology used as well as the methods used. Section 4 provides an example of how the proposed method can be applied. In Section 5, we provide a sensitivity analysis and comparative analysis the proposed method with existing methods. Section 6 presents the conclusion of this study.

2. Preliminaries

This section gives an overview of the definitions related to the Bipolar neutrosophic set (BNS), Heronian mean (HM), and Bipolar Neutrosophic Dombi-based Improved Generalized Weighted Heronian mean (BND-IGWHM) operators. These definitions are primarily used in integrating the BND-IGWHM operator into the DEMATEL method.

Definition 1. [21] Bipolar neutrosophic set
Let X be a nonempty set. A Bipolar neutrosophic set A is defined as follows:

$$A = \left\{ \left\langle x, T^{+}(x), I^{+}(x), F^{+}(x), T^{-}(x), I^{-}(x), F^{-}(x) \right\rangle : x \in X \right\}, \tag{1}$$

where $T^{+}, I^{+}, F^{+} : X \rightarrow [1,0]$ and $T^{-}, I^{-}, F^{-} : X \rightarrow [-1,0]$.
Here, the $T^{+}(x), I^{+}(x), F^{+}(x)$ represents positive membership degree, while $T^{-}(x)$, $I^{-}(x)$, $F^{-}(x)$ represents negative membership degree of an element $x \in X$.

Definition 2. [28] Deneutrosophication of BNS

Given that $A_{ij} = \left\langle t_{ij}^{+}, i_{ij}^{+}, f_{ij}^{+}, t_{ij}^{-}, i_{ij}^{-}, f_{ij}^{-} \right\rangle$ is a BNS. Deneutrosophication of A_{ij} is defined as follows:

$$\mu(A_{ij}) = 1 - \left[\frac{1}{2} \sqrt{\left(\frac{\left(1 - t_{ij}^{+}\right)^2 + \left(i_{ij}^{+}\right)^2 + \left(f_{ij}^{+}\right)^2}{3} \right) + \left(\frac{\left(1 - \left(-t_{ij}^{-}\right)\right)^2 + \left(-i_{ij}^{-}\right)^2 + \left(-f_{ij}^{-}\right)^2}{3} \right)} \right] \tag{2}$$

Definition 3. Bipolar Neutrosophic Dombi-based Improved Generalized Heronian mean (BND-IGWHM)

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

Consider $p,q \geq 0$, $\gamma > 0$, and let $A_{ij}^{K} = \left\langle t_{ij}^{+K}, i_{ij}^{+K}, f_{ij}^{+K}, t_{ij}^{-K}, i_{ij}^{-K}, f_{ij}^{-K} \right\rangle$ be a family of Bipolar neutrosophic sets with weight $w_k = (w_1, w_2, ..., w_m)^T$ satisfying $w_k \in [0,1]$ and $\sum_{r=1}^{m} w_k = 1$. Then, $BND-IGWHM^{p,q}$ is called (BND-IGWHM) operator and is indicated by $BND-IGWHM^{p,q}\left(A_{ij}^{1}, A_{ij}^{2}, ..., A_{ij}^{m}\right)$

$$= \frac{\left(\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s\, A_{ij}^{k\,p} \otimes A_{ij}^{sq}\right)^{\frac{1}{p+q}}}{\left(\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s\right)^{\frac{1}{p+q}}}$$

$$= \left\langle \left(1+\left(\left(\frac{\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s}{p+q}\right)\times 1/\left(\sum_{k=1}^{n}\sum_{k=r}^{n}\left(w_k\, w_s\, /\left(p\left(\frac{1-t_{ij}^{+k}}{t_{ij}^{+k}}\right)^{\gamma}\right)+\left(q\left(\frac{1-t_{ij}^{+s}}{t_{ij}^{+s}}\right)^{\gamma}\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1},\right.$$

$$1-\left(1+\left(\left(\frac{\sum_{r=1}^{m}\sum_{s=r}^{m} w_i\, w_j}{p+q}\right)\times 1/\left(\sum_{r=1}^{m}\sum_{s=r}^{m}\left(w_r\, w_s\, /\left(\left(p\left(\frac{i_{ij}^{+r}}{1-i_{ij}^{+r}}\right)^{\gamma}\right)+\left(q\left(\frac{i_{ij}^{+s}}{1-i_{ij}^{+s}}\right)^{\gamma}\right)\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1},$$

$$1-\left(1+\left(\left(\frac{\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s}{p+q}\right)\times 1/\left(\sum_{k=1}^{m}\sum_{s=k}^{m}\left(w_k\, w_s\, /\left(\left(p\left(\frac{f_{ij}^{+k}}{1-f_{ij}^{+k}}\right)^{\gamma}\right)+\left(q\left(\frac{f_{ij}^{+s}}{1-f_{ij}^{+s}}\right)^{\gamma}\right)\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1},$$

(3)

$$\left(1+\left(\left(\frac{\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s}{p+q}\right)\times 1/\left(\sum_{k=1}^{m}\sum_{s=k}^{m}\left(w_k\, w_s\, /\left(\left(p\left(\frac{-t_{ij}^{-k}}{1+t_{ij}^{-k}}\right)^{\gamma}\right)+\left(q\left(\frac{-t_{ij}^{-s}}{1+t_{ij}^{-s}}\right)^{\gamma}\right)\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1} -1,$$

$$-\left(1+\left(\left(\frac{\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s}{p+q}\right)\times 1/\left(\sum_{k=1}^{m}\sum_{s=k}^{m}\left(w_k\, w_s\, /\left(\left(p\left(\frac{1+i_{ij}^{-k}}{-i_{ij}^{-k}}\right)^{\gamma}\right)+\left(q\left(\frac{1+i_{j}^{-s}}{-i_{j}^{-s}}\right)^{\gamma}\right)\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1},$$

$$\left.-\left(1+\left(\left(\frac{\sum_{k=1}^{m}\sum_{s=k}^{m} w_k\, w_s}{p+q}\right)\times 1/\left(\sum_{k=1}^{m}\sum_{s=k}^{m}\left(w_k\, w_s\, /\left(\left(p\left(\frac{1+f_{ij}^{-k}}{-f_{ij}^{-k}}\right)^{\gamma}\right)+\left(q\left(\frac{1+f_{ij}^{-s}}{-f_{ij}^{-s}}\right)^{\gamma}\right)\right)\right)\right)\right)^{\frac{1}{\gamma}}\right)^{-1}\right\rangle$$

3. Proposed BND-IGWHM-DEMATEL

This section proposes a variant of DEMATEL known as Bipolar Neutrosophic Dombi-based Improved Generalized Heronian mean (BND-IGWHM) DEMATEL, which is particularly useful for solving groups of decision-making. The general framework of the BND-IGWHM-DEMATEL is illustrated in Figure 1.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

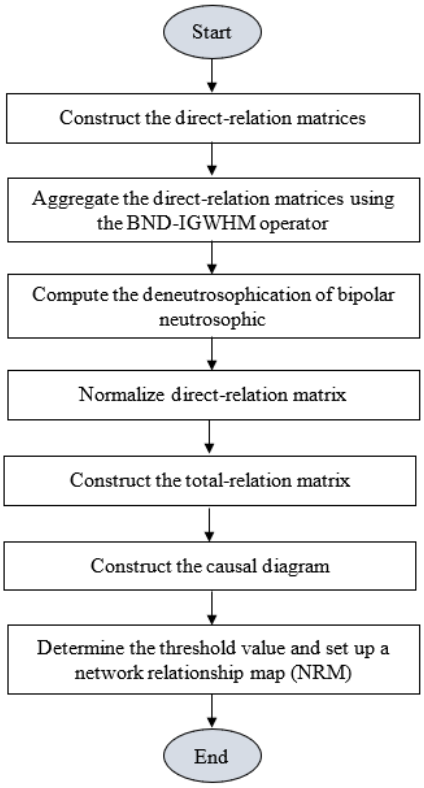

Figure 1: Framework of the proposed method.

Consider a MCDM problem with Bipolar neutrosophic information. Assume that there are n criteria of the problem defined as $C=\{C_1,C_2,...,C_n\}$. Suppose that $K=\{K_1,K_2,...,K_m\}$ is set of experts and $w_r=\{r=1,2,...,m\}$ is the corresponding weight of experts where $0\le w_r\le 1$ and $\sum_{r=1}^{m} w_r=1$. The criteria were evaluated by experts using the Bipolar neutrosophic linguistic variable developed by Rahim et al. [28] as shown in Table 1.

Algorithm

Step 1: Construct the direct-relation matrices.

Let $X^K=\left(A_{ij}^K\right)_{n\times n}$ be the direct-relation matrices given as

$$X^K=\left(A_{ij}^K\right)_{n\times n}=\begin{bmatrix} 0 & A_{12}^K & \cdots & A_{1n}^K \\ A_{21}^K & 0 & \cdots & A_{2n}^K \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1}^K & A_{n2}^K & \cdots & 0 \end{bmatrix}, \qquad (4)$$

where A_{ij} are the Bipolar neutrosophic linguistic variables representing the degree of influence between the criteria of i and j, assigned by the K-th expert. The option of Bipolar neutrosophic variables, ranging from "no influence (NI)" to "very high influence (VHI)", are listed in Table 1 below.

Table 1: Bipolar neutrosophic linguistic variables

Variable	BNS
No Influence (NI)	$(0.10,0.80,0.90,-0.10,-0.80,-0.90)$
Low Influence (LI)	$(0.35,0.60,0.70,-0.35,-0.60,-0.70)$

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

Medium Influence (MI)	$(0.50, 0.40, 0.45, -0.50, -0.40, -0.45)$
High Influence (HI)	$(0.80, 0.20, 0.15, -0.80, -0.20, -0.15)$
Very High Influence (VHI)	$(0.90, 0.10, 0.10, -0.90, -0.10, -0.10)$

Step 2: Aggregate the direct-relation matrices.

The direct-relation matrices in BNSs are aggregated using BND-IGWHM operator defined by Equation (3). The aggregated direct-relation matrix is denoted as A, such that

$$A = \left(A_{ij}\right)_{n\times n} = \begin{bmatrix} 0 & A_{12} & \cdots & A_{1n} \\ A_{21} & 0 & \cdots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \cdots & 0 \end{bmatrix}, \tag{5}$$

where $A_{ij} = BND-IGWHM^{p,q}\left(A_{ij}^{\ 1}, A_{ij}^{\ 2}, ..., A_{ij}^{\ m}\right)$

$$= \left\langle t_{ij}^{+}, i_{ij}^{+}, f_{ij}^{+}, t_{ij}^{-}, i_{ij}^{-}, f_{ij}^{-} \right\rangle,\ i, j = 1, 2, ..., n.$$

Step 3: Compute the deneutrosophication of Bipolar neutrosophic.

Deneutrosophication is the process of obtaining crisp numbers from Bipolar neutrosophic numbers. The element A_{ij} from aggregated matrix, A is calculated using Equation (2). Let A'_{ij} be a crisp number matrix, then the crisp matrix, A' is represented as follows:

$$A' = \left(A'_{ij}\right)_{n\times n} = \begin{bmatrix} 0 & A'_{12} & \cdots & A'_{1n} \\ A'_{21} & 0 & \cdots & A'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A'_{n1} & A'_{n2} & \cdots & 0 \end{bmatrix} \tag{6}$$

Step 4: Normalize the element from direct-relation matrix.

The normalized direct-relation matrix, D, is derived using Equation (7).

$$D = \frac{1}{s} A', \tag{7}$$

where

$$s = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} A'_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} A'_{ij} \right) \tag{8}$$

and the matrix D can be expressed as follows:

$$D = \left(A''_{ij}\right)_{n\times n} = \begin{bmatrix} 0 & A''_{12} & \cdots & A''_{1n} \\ A''_{21} & 0 & \cdots & A''_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A''_{n1} & A''_{n2} & \cdots & 0 \end{bmatrix} \tag{9}$$

From Equation (7) and (8), the element of $A''_{ij} = \dfrac{A'_{ij}}{\max\left(\max_{1\le i\le n} \sum_{j=1}^{n} A'_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} A'_{ij} \right)}$, where $0 \le A''_{ij} < 1$.

Step 5: Construct the total-relation matrix.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

The total-relation matrix, T can be acquired by using Equation (9) where I is an identity matrix, such that

$$T = D(I - D)^{-1} \tag{10}$$

Step 6: Construct the causal diagram.

The sum of the i^{th} rows (R_i) and the sum of j^{th} columns (C_j) of the total-relation matrix, T , are calculated using Equation (10) and Equation (11), respectively. The horizontal axis $\left(R_i + C_j\right)$, named "Prominence", shows the ranking of each criterion, while the vertical axis $\left(R_i - C_j\right)$, called "Relation", measures the cause-effect of the group. The statements indicate that a factor belongs to the causal group if the value of $\left(R_i - C_j\right)$ is positive and to the effect group if the value of $\left(R_i - C_j\right)$ is negative.

$$R_i = \left[R_i\right]_{n\times 1} = \sum_{j=1}^{n}\left[A'''_{ij}\right]_{n\times 1}\left(i = 1, 2, ..., n\right) \tag{11}$$

$$C_j = \left[C_j\right]_{1\times n} = \sum_{i=1}^{n}\left[A'''_{ij}\right]_{1\times n}\left(j = 1, 2, ..., n\right). \tag{12}$$

Step 7: Set up the threshold value and the network relationship map (NRM).

To explain the structural relation between criteria while keeping the complexity of the whole system at a manageable level, it is necessary to set a threshold value, t , which acts as a filter on negligible effected in the total-relation matrix. The value of t is determined by taking the average of the elements in the matrix T [46]. The elements in the matrix T are assumed to be zero if their values are less than t , meaning their influence is lower than those of the other criteria. Hence, a new total-relation matrix can be obtained, and a network relationship map can be constructed. The NRM can depict the true picture of the decision-making problem.

4. Illustrative Example

As an example, we consider the MCDM problems adapted from Liu et al. (2018). An organization is seeking the most suitable transport service provider for its logistics requirement. A group of four transportation experts evaluated five potential service providers based on the following criteria: ∂_1 - Reliability, ∂_2 - Business excellence, ∂_3 - Total cost, ∂_4 - Customer service, and ∂_5 - Green image. Experts are assigned to rate the criteria using the Bipolar neutrosophic linguistic scale presented in Table 1. Suppose the weight of vector of the experts is $w = (w_1, w_2, w_3, w_4)^T$ $= (0.2864, 0.2741, 0.2170, 0.1673)^T$ satisfying $0 \le w_1, w_2, w_3, w_4 \le 1$ and $\sum_{r=1}^{4} w_r = 1$.

Step 1: Construct the direct-relation matrices.

The evaluation of four experts X^1, X^2, X^3, X^4 based on linguistic variable in Table 1 are presented in the following matrices:

$$X^1 = \begin{bmatrix} 0 & VHI & HI & VHI & HI \\ HI & 0 & MI & MI & VHI \\ MI & MI & 0 & MI & VHI \\ HI & MI & MI & 0 & MI \\ MI & HI & MI & HI & 0 \end{bmatrix}, \quad X^2 = \begin{bmatrix} 0 & VHI & MI & VHI & HI \\ MI & 0 & MI & MI & HI \\ MI & MI & 0 & HI & VHI \\ HI & MI & MI & 0 & MI \\ NI & HI & MI & MI & 0 \end{bmatrix},$$

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

$$X^3 = \begin{bmatrix} 0 & VHI & MI & HI & MI \\ MI & 0 & VHI & MI & HI \\ MI & HI & 0 & MI & VHI \\ HI & MI & MI & 0 & MI \\ NI & HI & MI & MI & 0 \end{bmatrix}, \quad X^4 = \begin{bmatrix} 0 & HI & HI & VHI & LI \\ HI & 0 & VHI & MI & VHI \\ MI & HI & 0 & MI & VHI \\ VHI & MI & MI & 0 & MI \\ LI & HI & MI & HI & 0 \end{bmatrix}$$

Step 2: Aggregate the direct-relation matrices.

Aggregate the group experts' direct-relation matrices using the BND-IGWHM operator from Equation (3) based on their predetermined weight $w = (0.2864, 0.2741, 0.2170, 0.1673)$ and assume that $p = q = \gamma = 1$. The aggregated direct-relation matrix is shown in Table 2.

Table 2: Aggregated BNS initial direct-relation matrix.

Criteria	∂_1	∂_2	∂_3	∂_4	∂_5
∂_1	0	$(0.8883, 0.1117, 0.1068, -0.8866, -0.1134, -0.1073)$	$(0.6753, 0.2880, 0.2644, -0.6444, -0.3005, -0.3002)$	$(0.8838, 0.1162, 0.1093, -0.8813, -0.1187, -0.1101)$	$(0.7002, 0.2812, 0.2435, -0.6558, -0.3079, -0.3124)$
∂_2	$(0.6753, 0.2880, 0.2644, -0.6444, -0.3005, -0.3002)$	0	$(0.7430, 0.2275, 0.2428, -0.6589, -0.2723, -0.3054)$	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$	$(0.8574, 0.1426, 0.1233, -0.8526, -0.1474, -0.1245)$
∂_3	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$	$(0.6459, 0.3071, 0.2937, -0.6166, -0.3188, -0.3284)$	0	$(0.6149, 0.3271, 0.3253, -0.5870, -0.3386, -0.3589)$	$(0.9000, 0.1000, 0.1000, -0.9000, -0.1000, -0.1000)$
∂_4	$(0.8216, 0.1784, 0.1402, -0.8191, -0.1809, -0.1409)$	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$	0	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$
∂_5	$(0.2566, 0.6363, 0.7319, -0.1939, -0.6823, -0.8063)$	$(0.8000, 0.2000, 0.1500, -0.8000, -0.2000, -0.1500)$	$(0.5000, 0.4000, 0.4500, -0.5000, -0.4000, -0.4500)$	$(0.6753, 0.2880, 0.2644, -0.6444, -0.3005, -0.3002)$	0

As an illustration, the aggregated truth value t_{12}^{+} with respect to the pair of criteria ∂_1 and ∂_2 is calculated as:

$$t_{12}^{+} = \left(1 + \left(\frac{w_1 w_1 + w_1 w_2 + \ldots + w_4 w_4}{(1+1) \times \left(\frac{w_1 w_1}{(1)\left(\frac{1-0.9}{0.9}\right) + (1)\left(\frac{1-0.9}{0.9}\right)} + \frac{w_1 w_2}{(1)\left(\frac{1-0.9}{0.9}\right) + (1)\left(\frac{1-0.9}{0.9}\right)} + \ldots + \frac{w_4 w_4}{(1)\left(\frac{1-0.8}{0.8}\right) + (1)\left(\frac{1-0.8}{0.8}\right)}\right)}\right)^{\frac{1}{1}}\right)^{-1}$$

$$= \left(1 + \left(\frac{0.5624}{(1+1) \times (0.3691 + 0.3532 + \ldots + 0.0559)}\right)\right)^{-1}$$

$$= 0.8883$$

Note that the values for i_{12}^{+}, f_{12}^{+}, t_{12}^{-}, i_{12}^{-}, and f_{12}^{-} are derived in the same manner. As a result, $x_{12} = (0.8883, 0.1117, 0.1068, -0.8866, -0.1134, -0.1073)$.

Step 3: Compute the deneutrosophication of Bipolar neutrosophic.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

The deneutrosophication is performed using Equation (2), and the calculated values are displayed in Table 3.

Table 3: The deneutrosophication of BNS, A'

Criteria	∂_1	∂_2	∂_3	∂_4	∂_5
∂_1	0	0.4508	0.4882	0.4520	0.4866
∂_2	0.4882	0	0.4920	0.4816	0.4580
∂_3	0.4816	0.4894	0	0.4898	0.4477
∂_4	0.4642	0.4816	0.4816	0	0.4816
∂_5	0.4202	0.4673	0.4816	0.4882	0

Step 4: Normalize direct-relation matrix.

Based on Table 3, the normalized direct-relation matrix can be obtained using Equation (7) and Equation (8). The results of normalized matrix are shown in Table 4.

Table 4: The normalized direct-relation matrix, D

Criteria	∂_1	∂_2	∂_3	∂_4	∂_5
∂_1	0	0.2319	0.2512	0.2326	0.2504
∂_2	0.2512	0	0.2532	0.2478	0.2357
∂_3	0.2478	0.2518	0	0.2520	0.2304
∂_4	0.2389	0.2478	0.2478	0	0.2478
∂_5	0.2162	0.2405	0.2478	0.2512	0

Step 5: Construct the total-relation matrices.

The total-relation matrix, T, can be obtained using Equation (10), where I represents the identify matrices. Table 5 shows the total relation matrices T of the criteria.

Table 5: The total relation matrix, T

Criteria	∂_1	∂_2	∂_3	∂_4	∂_5
∂_1	7.4222	7.7231	7.9064	7.7951	7.6821
∂_2	7.7599	7.6735	8.0495	7.9448	7.8103
∂_3	7.7227	7.8391	7.8112	7.9117	7.7717
∂_4	7.7164	7.8363	8.0094	7.7102	7.7826
∂_5	7.5390	7.6665	7.8405	7.7444	7.4199

Step 6: Construct the causal diagram.

The values of C_j and R_i are derived using Equation (11) and (12), respectively. Based on these values, the prominence, $(R_i - C_j)$ and the relation, $(R_i + C_j)$ are determined and the results are displayed in Table 6.

Table 6: Prominence and relation degree of each criterion.

Criteria	C_j	R_i	$R_i + C_j$	Rank	$R_i - C_j$	Category
∂_1	38.5289	38.1602	76.6891	4	0.3687	Cause group
∂_2	39.2380	38.7385	77.9765	3	0.4995	Cause group
∂_3	39.0564	39.6170	78.6733	1	−0.5606	Effect group
∂_4	39.0550	39.1063	78.1612	2	−0.0513	Effect group
∂_5	38.2103	38.4666	76.6769	5	−0.2562	Effect group

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

Based on the Table 6 above, each criterion is categorized into cause-and-effect groups. Specifically, evaluation criteria with positive values of $\left(R_i - C_j\right)$, namely ∂_1, and ∂_2 belong to cause group. Meanwhile, criteria ∂_3, ∂_4, and ∂_5 are classified in the effect group as their values of $\left(R_i - C_j\right)$ is negative. Figure 2 presents the cause-effect diagram such that the points representing the criteria are plotted based on their $\left(R_i + C_j\right)$ and $\left(R_i - C_j\right)$ values.

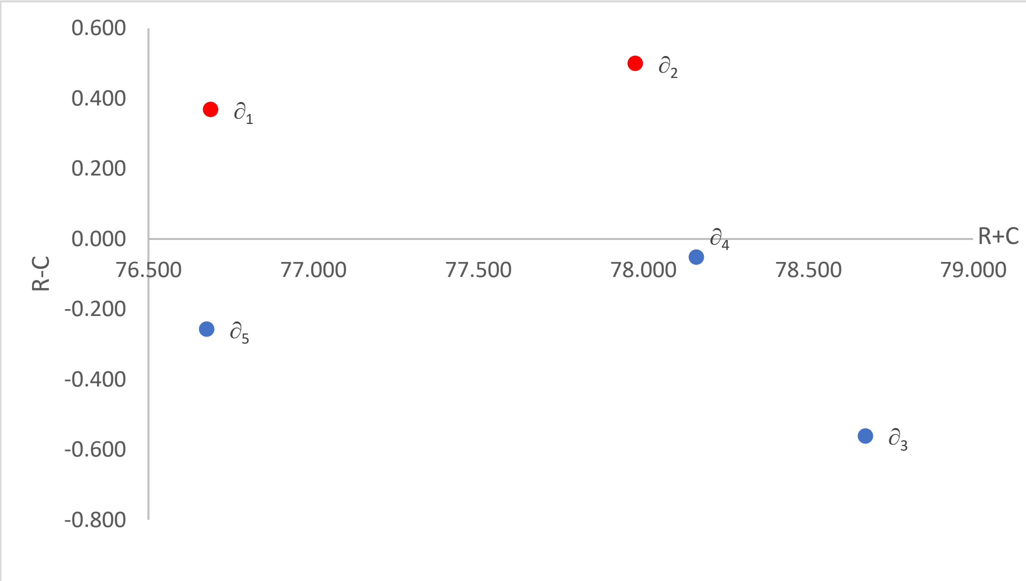

Figure 2: The causal diagram.

Step 7: Determine the threshold value and set up a network relationship map (NRM).

The threshold value is determined based on the average of the total relation matrix, which is t=7.7635. A new total relational matrix is then formed. If the corresponding entries of the total relation matrix are greater than t, then the element of the new total relation matrix is 1. Otherwise, the element is assigned as 0.

Table 7: The new total relation matrix.

Criteria	∂_1	∂_2	∂_3	∂_4	∂_5
∂_1	0	0	1	1	0
∂_2	0	0	1	1	1
∂_3	0	1	1	1	1
∂_4	0	1	1	0	1
∂_5	0	0	1	0	0

Then, a network relationship map (NRM) is constructed based on Table 7 to visualize the relationship between criteria. The relationship between influences is illustrated in Figure 3. Contrastingly, the causal diagram presented in Figure 2 implies that business excellence (∂_2) emerges as the most pivotal influencing criterion, given its highest intensity of relationship with other factors. This assertion can be further examined by analyzing the obtained values of the $\left(R_i - C_j\right)$ measure.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

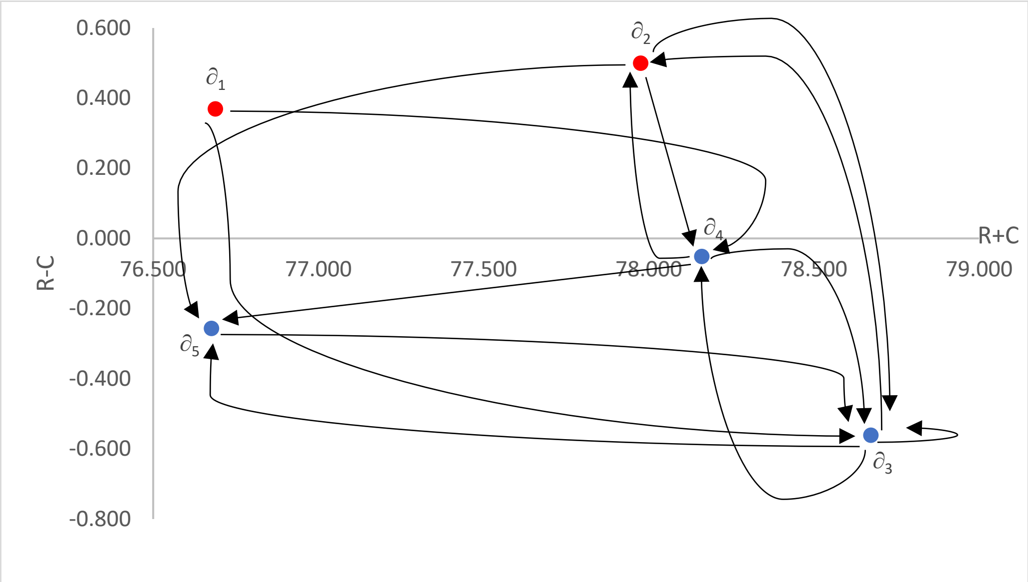

Figure 3: Network relationship map.

From Figure 3, it can be seen that the criteria are interrelated and easily affected by other criteria. For example, ∂_1 is not affected by the other criteria but is impacted by two criteria, ∂_4 and ∂_3. A similar situation exists for ∂_4, which impacts all criteria except ∂_1 and is affected by ∂_1, ∂_2, and ∂_3. Conversely, ∂_5 is the least important criterion since it has the lowest $\left(R_i + C_j\right)$ value and only influences one criterion, which is ∂_3. Generally, any combination of the criteria ∂_2, ∂_3, and ∂_4 commonly influences other criteria. Criteria ∂_3 may have direct influence with all criteria except ∂_1, which is easily affected by the other four criteria and itself. Hence, the best transport services provider is determined by ∂_3 (total cost) since it is the criterion that most affects the other criteria and also has the highest $\left(R_i + C_j\right)$ value.

5. Results and Discussion

This section consists of two parts. In the first part, a sensitivity analysis is conducted to investigate the impact of parameter variations on the Dombi and HM aggregation operator ($p, q,$ and γ) on BND-IGWHM calculations. Meanwhile, in the second part, a comparison is carried out between the proposed method (BND-IGWHM-DEMATEL) and existing methods namely the classical DEMATEL, SVNS-DEMATEL, and BNS-DEMATEL that employ arithmetic mean aggregation.

5.1 Sensitivity analysis

The parameters γ in Dombi TN and Dombi TCN are crucial for controlling the flexibility of the aggregation process. Additionally, it allows the behaviour of the aggregation rule to be modified based on various BNS situations and preferences. Table 8 shows the results according to the ordering of criteria and the categorization of the cause-and-effect group for the different parameters of γ based on the Bipolar neutrosophic Dombi-based improved generalized weighted Heronian mean (BND-IGWHM) aggregation operator (Parameters p and q remain constant, at $p = q = 1$).

Table 8: The ranking orders of criteria for different γ values.

γ	**Ranking**	**Category**	
		Cause group	Effect group
2	$\partial_3 \succ \partial_2 \succ \partial_4 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
3	$\partial_3 \succ \partial_2 \succ \partial_4 \succ \partial_1 \succ \partial_5$	$\partial_1, \partial_2, \partial_5$	∂_3, ∂_4
7	$\partial_3 \succ \partial_2 \succ \partial_4 \succ \partial_1 \succ \partial_5$	$\partial_1, \partial_2, \partial_5$	∂_3, ∂_4
10	$\partial_3 \succ \partial_2 \succ \partial_1 \succ \partial_4 \succ \partial_5$	$\partial_1, \partial_2, \partial_5$	∂_3, ∂_4

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

20	$\partial_3 \succ \partial_2 \succ \partial_1 \succ \partial_4 \succ \partial_5$	$\partial_1, \partial_2, \partial_5$	∂_3, ∂_4

The ranking orders of criteria based on the BND-IGWHM operator are slightly different when the γ is greater than or equal to 10, but the mostly preferred criteria remain identical. For $2 \le \gamma \le 7$, the ranking orders are shown as $\partial_3 \succ \partial_2 \succ \partial_4 \succ \partial_1 \succ \partial_5$ and meanwhile for parameters $8 \le \gamma \le 20$, the ranking orders of criteria stated as $\partial_3 \succ \partial_2 \succ \partial_1 \succ \partial_4 \succ \partial_5$. Regardless of the γ values, the best option remains ∂_3.

Next, to illustrate the influence of parameters p and q on decision-making in this example, we use the different values p and q using the BND-IGWHM method to rank the criteria. Assume that parameter γ is a constant where $\gamma = 1$. Hence, the ranking orders are shown in Table 9.

Table 9: The ranking orders of criteria for different p and q values.

p*,*q	**Ranking**	**Category**	
		Cause group	Effect group
1,0	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_2, ∂_5	$\partial_1, \partial_3, \partial_4$
1,0.5	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
1,2	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
0,1	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
0.5,1	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
2,1	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
2,2	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$

The results in Table 9 show that the ranking orders and the best criteria remain the same that is $\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$. The most crucial criterion is ∂_3, while the least important is ∂_5. In terms of cause-and-effect, the elements of the corresponding groups are similar for all pairs of p and q except for $p = 1$ and $q = 0$.

5.2 Comparative analysis

In this section, the comparison analysis is performed to assess the ranking orders obtained using the proposed method and some existing methods namely, the classical DEMATEL [47], SVNS-DEMATEL [16], and the BNS-DEMATEL [27] with arithmetic mean operator. Table 10 below shows the ranking order of criteria obtain from different methods.

Table 10: The ranking orders based on different methods.

Method	**Ranking**	**Category**	
		Cause group	Effect group
Classical DEMATEL [47]	$\partial_2 \succ \partial_1 \succ \partial_3 \succ \partial_5 \succ \partial_4$	∂_1, ∂_3	$\partial_2, \partial_4, \partial_5$
SVNS-DEMATEL [16]	$\partial_4 \succ \partial_3 \succ \partial_5 \succ \partial_2 \succ \partial_1$	$\partial_1, \partial_3, \partial_4, \partial_5$	∂_2
BNS-DEMATEL [27]	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$
Proposed method	$\partial_3 \succ \partial_4 \succ \partial_2 \succ \partial_1 \succ \partial_5$	∂_1, ∂_2	$\partial_3, \partial_4, \partial_5$

Note that the ranking order derived from classical DEMATEL differs significantly from the rest of the methods. Classical DEMATEL do not consider the aspect of uncertainty and incomplete information in the decision-making process since it uses crisp set to represent relationships among factors or criteria. Crisp sets are sets where each element either belongs or does not belong to the set without any ambiguity or uncertainty. Besides, the integration of classical DEMATEL does not consider the interrelationship between criteria because the standard practice uses the average mean in the aggregation process [48].

In contrast, the SVNS is designed to capture both membership and non-membership degrees [49]. However, it primarily focuses on describing positive membership degrees, unlike the BNS, which can

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

handle both positive and negative membership degrees. From the table, the ranking order obtained using SVNS-DEMATEL is slightly different, with ∂_4 as the best option and ∂_1 as the least option. The existing method by Liu et al. [16] used a weighted average to aggregate the information into the DEMATEL method. The results show that BNS-DEMATEL and the proposed method are consistent. For both methods, show that ∂_3 turns out to be the most crucial criterion. Note that in the BNS-DEMATEL [27], decision-maker judgments are aggregated using the arithmetic mean. This method averages the input arguments without taking into account for their interrelationships. In contrast, the proposed method thoroughly examines the intricate relationships among the input arguments throughout the aggregation process.

6. Conclusion

In conclusion, this study proposed an integrated DEMATEL approach, combining Bipolar neutrosophic Dombi with DEMATEL with improved generalized weighted Heronian mean aggregation operator to assess the selection of a transportation service provider. The proposed methods allow a more comprehensive analysis of causal relationships among the identified factors. This method takes into consideration the interrelationships between input arguments and variable operational parameters to aggregate information within the Bipolar Neutrosophic Sets (BNS) environment. The application of BNS proves instrumental in addressing the situation's positive and negative aspects. Furthermore, DEMATEL analysis played a crucial role in identifying factors that impact the decision-making process and are influenced by other factors. Sensitivity analysis and comparison with existing methods are also provided to select the best transportation service provider.

For future research, the proposed aggregate procedure may potentially be integrated with other alternative ranking methods such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Analytic Hierarchy Process (AHP).

Acknowledgments: This paper is funded by the Universiti Teknologi MARA (UiTM) through the MyRA Research Grant LPHD with grant file number 600-RMC/GPM LPHD 5/3 (056/2023).

Conflicts of Interest: "The authors declare no conflict of interest."

References

[1] Renzi, C., Leali, F., & Di Angelo, L. (2017). A review on decision-making methods in engineering design for the automotive industry. *Journal of Engineering Design*, *28*(2), 118-143.

[2] Mardani, A., Hooker, R. E., Ozkul, S., Yifan, S., Nilashi, M., Sabzi, H. Z., & Fei, G. C. (2019). Application of decision making and fuzzy sets theory to evaluate the healthcare and medical problems: a review of three decades of research with recent developments. *Expert Systems with Applications*, *137*, 202-231.

[3] Yao, S. (2021). Fuzzy-based multi-criteria decision analysis of environmental regulation and green economic efficiency in a post-COVID-19 scenario: the case of China. *Environmental Science and Pollution Research*, *28*, 30675-30701.

[4] Garai, T., & Garg, H. (2022). Multi-criteria decision making of water resource management problem (in Agriculture field, Purulia district) based on possibility measures under generalized single valued non-linear bipolar neutrosophic environment. *Expert Systems with Applications*, *205*, 117715.

[5] Chirra, S., & Kumar, D. (2018). Evaluation of supply chain flexibility in automobile industry with fuzzy DEMATEL approach. *Global Journal of Flexible Systems Management*, *19*(4), 305-319.

[6] Gabus, A., & Fontela, E. (1972). World problems, an invitation to further thought within the framework of DEMATEL. Switzerland, Geneva: Battelle Geneva Research Centre

[7] Si, S. L., You, X. Y., Liu, H. C., & Zhang, P. (2018). DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. *Mathematical Problems in Engineering*, *2018*, 1-33.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

[8] Zadeh, L.A. (1965). Fuzzy sets. *Inf. Cont.*, *8*, 338–353.

[9] Mahmoudi, S., Jalali, A., Ahmadi, M., Abasi, P., & Salari, N. (2019). Identifying critical success factors in Heart Failure Self-Care using fuzzy DEMATEL method. *Applied Soft Computing*, *84*, 105729.

[10] Suzan, V., & Yavuzer, H. (2020). A Fuzzy Dematel Method to evaluate the most common diseases in internal medicine. *International Journal of Fuzzy Systems*, *22*, 2385-2395.

[11] Ghadami, L., Masoudi Asl, I., Hessam, S., & Modiri, M. (2021). Developing hospital accreditation standards: applying fuzzy DEMATEL. *International Journal of Healthcare Management*, *14*(3), 847-855.

[12] Kamalov, F., Gheisari, M., Liu, Y., Feylizadeh, M. R., & Moussa, S. (2023). Critical Controlling for the Network Security and Privacy Based on Blockchain Technology: A Fuzzy DEMATEL Approach. *Sustainability*, *15*(13), 10068.

[13] Seker, S., & Zavadskas, E. K. (2017). Application of fuzzy DEMATEL method for analyzing occupational risks on construction sites. *Sustainability*, *9*(11), 2083.

[14] Ocampo, L., & Yamagishi, K. (2020). Modeling the lockdown relaxation protocols of the Philippine government in response to the COVID-19 pandemic: An intuitionistic fuzzy DEMATEL analysis. *Socio-economic planning sciences*, *72*, 100911.

[15] Smarandache, F. (1998). Neutrosophy: neutrosophic probability, set, and logic: analytic synthesis & synthetic analysis. Rehoboth, N. M.: *American Research Press.*

[16] Liu, F., Aiwu, G., Lukovac, V., & Vukic, M. (2018). A multicriteria model for the selection of the transport service provider: A single valued neutrosophic DEMATEL multicriteria model. *Decision Making: Applications in Management and Engineering*, *1*(2), 121-130.

[17] Abdel-Basset, M., Manogaran, G., Gamal, A., & Smarandache, F. (2018). A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria. *Design Automation for Embedded Systems*, *22*, 257-278.

[18] Abdel-Basset, M., Atef, A., & Smarandache, F. (2019). A hybrid Neutrosophic multiple criteria group decision making approach for project selection. *Cognitive Systems Research*, *57*, 216-227.

[19] Kilic, H. S., Yurdaer, P., & Aglan, C. (2021). A leanness assessment methodology based on neutrosophic DEMATEL. *Journal of Manufacturing Systems*, *59*, 320-344.

[20] Mamites, I., Almerino, P., Sitoy, R., Atibing, N. M., Almerino, J. G., Cebe, D., ... & Ocampo, L. (2022). Factors Influencing Teaching Quality in Universities: Analyzing Causal Relationships Based on Neutrosophic DEMATEL. *Education Research International*, *2022*.

[21] Deli, I., Ali, M., & Smarandache, F. (2015, August). Bipolar neutrosophic sets and their application based on multi-criteria decision-making problems. *International conference on advanced mechatronic systems*, 249-254.

[22] Wang, L., Zhang, H. Y., & Wang, J. Q. (2018). Frank Choquet Bonferroni mean operators of bipolar neutrosophic sets and their application to multi-criteria decision-making problems. *International Journal of Fuzzy Systems*, *20*, 13-28.

[23] Mahmood, M. K., Zeng, S., Gulfam, M., Ali, S., & Jin, Y. (2020). Bipolar neutrosophic dombi aggregation operators with application in multi-attribute decision making problems. *IEEE access*, *8*, 156600-156614.

[24] Gulfam, M., Mahmood, M. K., Smarandache, F., & Ali, S. (2021). New Dombi aggregation operators on bipolar neutrosophic set with application in multi-attribute decision-making problems. *Journal of Intelligent & Fuzzy Systems*, *40*(3), 5043-5060.

[25] Jamil, M., Afzal, F., Akgül, A., Abdullah, S., Maqbool, A., Razzaque, A., ... & Awrejcewicz, J. (2022). Einstein Aggregation Operators under Bipolar Neutrosophic Environment with Applications in Multi-Criteria Decision-Making. *Applied Sciences*, *12*(19), 10045.

[26] Awang, A., Ghani, A. T. A., Abdullah, L., & Ahmad, M. F. (2018, June). A DEMATEL method with single valued neutrosophic set (SVNS) in identifying the key contribution factors of Setiu Wetland's coastal erosion. In *AIP conference proceedings* (Vol. 1974, No. 1). AIP Publishing.

[27] Abdullah, L., & Rahim, S. N. (2020). Bipolar neutrosophic DEMATEL for urban sustainable development. *Journal of Intelligent & Fuzzy Systems*, *39*(5), 6109-6119.

[28] Rahim, N., Abdullah, L., & Yusoff, B. (2020). A border approximation area approach considering bipolar neutrosophic linguistic variable for sustainable energy selection. *Sustainability*, *12*(10), 3971.

[29] Tripathi, S., & Gupta, M. (2021). Identification of challenges and their solution for smart supply chains in Industry 4.0 scenario: a neutrosophic DEMATEL approach. International Journal of Logistics Systems and Management, 40(1), 70-94.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024

[30] Saleh, W. A., Abdelkaderb, S. M., Rashada, H., & Abdelgawad, A. (2023). Analyzing Critical Success Factors of IoT-Enabled Green Supply Chain Management Using Bipolar Neutrosophic-DEMATEL. *Neutrosophic Sets and Systems*, *55*(1), 8.
[31] Choquet, G. (1953). Theory of capacities. In Annales de l'Institut Fourier, 5, 131-295
[32] Yager, R. R. (2001). The power average operator. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans, 31(6), 724-731.
[33] Chiclana, F., Herrera, F., & Herrera-Viedma, E. (2002). The ordered weighted Geometric operator: properties and application in MCDM problems. *In Technologies for constructing intelligent systems*, 2, 173-183.
[34] Bonferroni, C. (1950). Sulle medie multiple di potenze. Bollettino dell'Unione Matematica Italiana, 5(3-4), 267-270.
[35] Beliakov, G., Pradera, A., & Calvo, T. (2007). *Aggregation functions: A guide for practitioners* (Vol. 221). Heidelberg: Springer.
[36] Xu, Z. (2009). Fuzzy harmonic mean operators. *International Journal of Intelligent Systems*, *24*(2), 152-172.
[37] Liu, H. Z., & Pei, D. W. (2012). HOWA operator and its application to multi-attribute decision making. *Journal of Zhejiang Sci-Tech University*, *25*, 138-142.
[38] Yu, D.J. (2013). Intuitionistic fuzzy geometric Heronian mean aggregation operators. Applied Soft Computing, 13(2), 1235–1246.
[39] Li, Y., Liu, P., & Chen, Y. (2016). Some single valued neutrosophic number heronian mean operators and their application in multiple attribute group decision making. Informatica, 27(1), 85-110.
[40] Liu, P., & Zhang, L. (2017). Multiple criteria decision making method based on neutrosophic hesitant fuzzy Heronian mean aggregation operators. Journal of Intelligent & Fuzzy Systems, 32(1), 303-319.
[41] Fan, C., Ye, J., Feng, S., Fan, E., & Hu, K. (2019). Multi-criteria decision-making method using heronian mean operators under a bipolar neutrosophic environment. Mathematics, 7(1), 97.
[42] Hu, X., Yang, S., & Zhu, Y. R. (2022). Multiple-attribute decision making based on interval-valued intuitionistic fuzzy generalized weighted heronian mean. Information, 13(3), 138.
[43] Dombi, J. (1982). A general class of fuzzy operators, the DeMorgan class of fuzzy operators and fuzziness measures induced by fuzzy operators. *Fuzzy sets and systems*, *8*(2), 149-163.
[44] Awang, A., Ghani, A. A., Abdullah, L., & Ahmad, M. F. (2018, November). The Shapley weighting vector-based neutrosophic aggregation operator in DEMATEL method. In Journal of Physics: Conference Series (Vol. 1132, p. 012059). IOP Publishing.
[45] Abdullah, L., Zulkifli, N., Liao, H., Herrera-Viedma, E., & Al-Barakati, A. (2019). An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management. Engineering Applications of Artificial Intelligence, 82, 207-215.
[46] Altuntas, S., & Dereli, T. (2015). A novel approach based on DEMATEL method and patent citation analysis for prioritizing a portfolio of investment projects. *Expert systems with Applications*, *42*(3), 1003-1012.
[47] Kiani Mavi, R., & Standing, C. (2018). Cause and effect analysis of business intelligence (BI) benefits with fuzzy DEMATEL. Knowledge Management Research & Practice, 16(2), 245-257
[48] Chen, J. K. (2021). Improved DEMATEL-ISM integration approach for complex systems. *Plos one*, *16*(7), e0254694.
[49] Ye, J. (2017). Single-valued neutrosophic clustering algorithms based on similarity measures. Journal of Classification, 34(1), 148-162.

DOI: https://doi.org/10.54216/IJNS.250101
Received: December 05, 2023 Revised: February 01, 2024 Accepted: May 24, 2024