A Hybrid Neutrosophic Approach of DEMATEL with AR-DEA in Technology Selection

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Abstract: Technology selection is a leading step for decision makers throughout the technology selection process. The extraction of convenient technology is pretended to be a real challenge that faces decision makers. The technology selection considers the qualitative and quantitative criteria which needs to a special representation due to the conditions of non-compensation and uncertainty on real life. The objectives of this study is to make a hybrid approach using decision making trial and evaluation laboratory (DEMATEL) for detecting the positive and negative regions, and assurance region data envelopment analysis (AR-DEA) for evaluating the efficiency of Decision Making Units (DMUs). The hybrid model is protracted with neutrosophic philosophy in representing the perspectives of specialists and experts to achieve the most optimized outputs. An illustrative case study, about technology revolution and digital transformation in EGYPT, is presented to demonstrate the proposed model.

Keywords: Neutrosophic sets; Technology Selection; DEMATEL; Assurance Region; Data Envelopment Analysis.

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1. Introduction

Technology has been an innovative manner that facilitates human life activities in real life. The selection of the appropriate technology is pretended to be a hard targets for experts. The selected technology will directly influence on the competitive advantages for organizations. Indeed, technology not only has valuable benefits, but also has susceptible weakness. Due to the technology complexity of operational and strategic distinctive, the technology selection can aids decision makers to build a vision to be able to choose the appropriate candidates of technologies [1]. The technology can be prescribed in many dimensionality terms such as cost, flexibility, quick delivery, and time [2].

The process of technology selection addressed by multiple methodologies over time, the classical approaches used was the mathematical programming [3]. The mathematical programming objective is to select the most convenient technology with lowest production cost by the use of non-linear 0-1 programming model [4]. Considering the complexity of technology selection, a fuzzy GP approach is presented to select the most appropriate machine tool and to allocate to a flexible manufacturing systems technology [5]. Data envelopment analysis (DEA) is a nonparametric efficiency method, such that data is not necessary to fit normal distribution [6]. The DEA can be used efficiently in technology selection. The DEA can assign weights for inputs and outputs to achieve to the maximum level of efficiency. In [7] presents a methodology consists of two phases for solving the technology problem process. The first phase, the data envelopment analysis (DEA) is focused on extracting the best vendor's solutions with respect to various technology parameters. The second stage, multi-attribute decision making model is used to prioritize and metric the outputted technology selection from first phase. The objective of decision-making units (DMUs) is to be efficient by producing the maximized outcomes and minimized incomes. The efficiency of DMUs can be evaluated with DEA as a powerful tool. In DEA, the input and outputs must be determined. In [8] proposes an innovative model, IDEA (Imprecise Data Envelopment Analysis) model to rank the technology suppliers. In [9] illustrated a weight multi-criteria decision-making (MCDM) methodology to evaluate the relative efficiency of DMUs according to various outputs and one determined input. The efficiency of DUMs is a model derived from of DEA methodology to extract exact and ordinal outcomes. When importance of preferences information between inputs and outputs are combined in multiple models, the resulted model is called Assurance region (AR) models. The efficiency problem includes technological and commercial aspects. A study about Superconducting Super Collider (SSC) in United States is conducted to reduce the number of site location [10]. By applying DEA on case study's data, the output included five out of six solutions were efficient. However, by including more analytical bounds, AR decreased the output to be one out of six. The AR is applied in another case study, about an efficient analysis for the possible linear production sets to make a real reduction on candidates [11].

The process of technology selection includes many technical and operational comparisons such as: cost, capacity, load, velocity, and etc. Many studies focus on the efficiency to enhance the decisions for the technology selection [12, 13]. The DEMTAL is a kind of structural modeling suggested to solve complex and interrelated problems [12]. The DEMTAL can formulate and analyze the problem into relationships between the correlated and complex criterions in order to attain the best solutions. Many decision-making methods are provided to organizations to choose the best technology [1, 3, 4, 7, 8]. However, the statement of any decision is a surrounded with environment of vague, impression, inconsistency, and uncertainty. According to the complex considerations of the environmental conditions in technology selection, researchers integrate fuzzy to DEMATEL method to attain more accurate analysis [14-17]. Actually, the fuzzy set considered the degree of membership function and neglected the degree of non- membership, and indeterminate [18]. Hence, the fuzzy DEMTAL con not addressed the decisions which are associated with uncertainty and inconsistency. To overcome fuzzy set limitations, neutrosophic sets proposed to address the conditions of uncertainty and inconsistency [19, 33-39].

Neutrosophic sets are a novel aspect in philosophy that investigates the scope and origin of neutralities [20, 21]. The neutrosophic sets are used in many complex applications and achieved awesome results such as in IoT influential factors [22] , IoT Transitions difficulties on enterprises [19] personnel selection [23], cloud services [24], supplier selection [18, 25-27], supply chain management (SCM) [25]. In real life situations, the preferences and correlations between criterions cannot be easily determined by decision makers. Hence neutrosophic can deal with uncertainty and inconsistency conditions. Neutrosophic aids decision makers to find compensations methodology to the indeterminate decision cases. Therefore, the research aims to propose a novel methodology that integrates the assurance region- data envelopment analysis (AR-DEA) with neutrosophic DEMTAL to enhance the technology selection process. Some basic and important definitions about neutrosophic sets are provided in [22].

For clarity, the reset of research is organized as follows: Section 2 mentions neutrosophic DEMTAL methodology. Section 3 represents basic steps of (AR-DEA). Section 4 illustrates the integrated methodology for technology selection. Section 5 presents a numerical example. Finally, section 6 ends with the conclusions and future work.

2. The Neutrosophic DEMATEL Methodology

The neutrosophic sets developed to cover the current conditional environmental of uncertainty and inconsistency that cannot be covered with other methods such as fuzzy and intuitionistic fuzzy [28]. The neutrosophic sets can apply compensatory methods for the indeterminate situations for decision judgments. DEMATEL is a methodology used to analyze the preferences between complex criterions by building well-structural model [2]. It is very hard task to take decision of preferences of various criterions. Hence, the research proposes to extend the traditional DEMTEL with neutrosophic set theory in order add valuable advantages:

1. Neutrosophic can present various expert judgments for a specific problem.
2. Neutrosophic can support perspectives of experts with compensatory values for the degree of true, false decisions. In addition to indeterminate decisions.
3. Neutrosophic can definitely represent different expert's perspectives to demonstrate if any anomalies found in the general judgments, such as: less experience, or biasness.
4. Neutrosophic can represent expert judgments in real situations of uncertainty and inconsistency of information

Therefore, the current study integrates neutrosophic with DEMATEL methodology in order to attain more accurate analysis. The steps of neutrosophic DEMATEL are mentioned as follows:

Step 1. Determine the aim of your study and detect the following issues:

- The decision maker experts in the proposed study.
- Identify the basic criterions related to study

Step 2. Construct decision judgments of the current study in a pairwise comparison matrix

- Construct the pairwise comparison matrix from decision judgments for the preferences scale mentioned in Table 1 [23]. Experts should determine their perspectives and expectation of the problem to detect maximum truth, minimum indeterminacy, and minimum false membership function.

Table 1. The Linguistics phrase and corresponding NTS

Score	*Linguistic Phrase*	*NTS*
1	Equally significant	$1 = \langle\langle 1, 1, 1\rangle; 0.50, 0.50, 0.50\rangle$
3	Slightly significant	$3 = \langle\langle 2, 3, 4\rangle; 0.30, 0.75, 0.70\rangle$
5	Strongly significant	$5 = \langle\langle 4, 5, 6\rangle; \langle 0.80, 0.15, 0.20\rangle$
7	very strongly significant	$7 = \langle\langle 6, 7, 8\rangle, 0.90, 0.10, 0.10\rangle$
9	Absolutely significant	$9 = \langle\langle 9, 9, 0\rangle; 1.00, 0.00, 0.00\rangle$
2	sporadic values between two close scales	$2 = \langle\langle 1, 2, 3\rangle; 0.40, 0.60, 0.65\rangle$
4		$4 = \langle\langle 3, 4, 5\rangle; 0.35, 0.60, 0.40\rangle$
6		$6 = \langle\langle 5, 6, 7\rangle; 0.70, 0.25, 0.30\rangle$
8		$8 = \langle\langle 7, 8, 9\rangle; 0.85, 0.10, 0.15\rangle$

Step 3. Construct initial direct relation

- Construct a general vision for your study from aggregating decision makers' perspectives. The averaged aggregated pairwise comparison matrix is formulated by the use of the following equation r_{ij} .

$$r_{ij} = \frac{\sum_{z=1}^{z} (z_{ij}^{\ z})}{z} \qquad (1)$$

- The general vision are constructed by the estimated preferences and resulted in an aggregated pairwise comparison matrix as follows in (2):

$$A = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{mn} \end{pmatrix} \qquad (2)$$

- Change the aggregates pairwise comparison matrix from the form of triangular neutrosophic scale to the form of crisp value by the use of the following score function [19]:

$$s(r_{ij}) = \left| l_{ij} \times m_{j} \times u_{ij} \right) \frac{T_{ij} + I_{ij} + F_{ij}}{9} \Bigg| , \qquad (3)$$

where l, m, u denotes lower, median, upper of the scale neutrosophic numbers, T, I, F are the truth-membership, indeterminacy, and falsity membership functions respectively of triangular neutrosophic number.

Step 4. **Construct the normalized direct relation matrix**

The initial direct relation is represented in the form of (2). According to previous step (3), the normalized direct relation matrix can be computed as follows:

$$B= 1 \Big/ \max_{1 \le i \le m} \sum_{j=1}^{n} r_{ij} \, ; i = 1,2,3,\ldots m; \; j = 1,2,3,\ldots,n \qquad (4)$$

$$Y = B \times R \qquad (5)$$

Step 5. **Obtain the total relation matrix.**

Apply the following equation to produce the total relation matrix from the generalized direct relation matrix Y. The total matrix relation is computed as follows [12]:

$$\sum_{n=1}^{\infty} Y_i = Y + Y^2 + Y^3 \ldots Y^m$$

$$= Y(1 + Y + Y^2 + \ldots + Y^{n-1})$$

$$= Y(I - Y)^{-1}(I - Y)(I + Y + Y^2 + \ldots + Y^{n-1})$$

$$= Y(1 - Y)^{-1}(I - Y^n) = Y(I - Y)^{-1}$$

$$T = Y \times (I - Y)^{-1} \quad , \tag{6}$$

such that I denotes to identity matrix, and T is the matrix of total relation

Step 6. Identify the cause effect relationship using the function of summation of rows and columns

The cause effect relationship is detected by using the summation of rows (R_i), of columns (C_j) form total matrix relation T as follows in next equations [14]:

$$T = \lfloor t_{ij} \rfloor_{m \times m}; i, j = 1,2,\ldots n \tag{7}$$

$$R_i = \sum_{1 \le j \le m}^{m} t_{ij}, \forall i \tag{8}$$

$$C_j = \sum_{1 \le i \le n} t_{ij}, \forall j \tag{9}$$

Step 7. Build the casual effect relationship diagram

The analysis of cause effect diagram two axes denotes the followings:

- **Horizontal axes:** represents the summation of rows and columns ($R_i + C_j$), and refers to the importance of the proposed criteria.
- **Vertical axes:** represents the subtraction of rows and columns ($R_i - C_j$), and refers to the degree of influence of the selected criteria

3. The AR-DEA methodology

Considering the whole decision maker units (DMU) in the decision maker process for AR-DEA methodology, the decision maker is influenced with other complementary players such as [28] and modeled in Fig.1:

- **Buyers:** anybody requests for a service according to considered contract. .
- **Users:** anybody actually receives and use the service.
- **Influencers**: anybody affects sales by supplying information or advice
- **Gatekeepers:** anybody controls the follow of information for the suppliers.

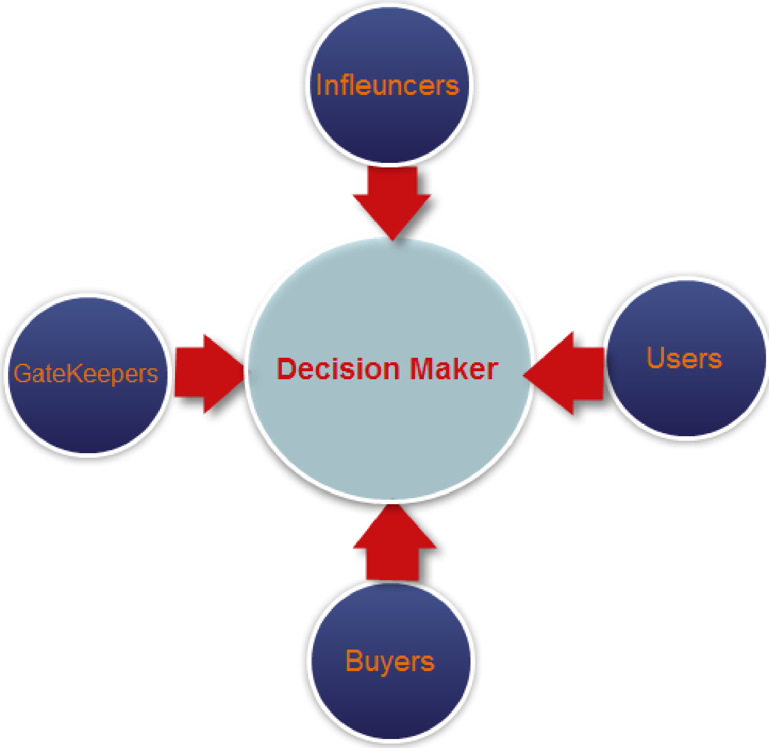

Figure 1. Decision makers unit

The DEA is an approach used to evaluate the efficiencies for DMUs [6]. The challenge in DMUs of technology selection is the absence for decision maker's judgments and preferences. The weight restriction inclusion in DEA model allows the integration of relative important between inputs and outputs for technology selection problem. The extension of DEA method with further calculations led to the development of the AR model [10]. The AR introduces a domain of possible candidates for multiple virtual suppliers. The next steps are discussed the scale of input and output levels, NB. The DMUs are strict to be in positive manner.

Step 8: Transform problem scale from ordinal to interval

The proposed study uses a novel weight technique which is so-called ordinal weight restriction assurance region [2]. The decision problem affected with various incomes and outcome. By the use of neutrosophic DEMATEL, the input and output weights can be obtained by the following equations:

$$X_1 \geq X_2 \geq \cdots \geq X_i \quad (10)$$

$$Y_1 \geq Y_2 \geq \cdots \geq Y_j \quad (11)$$

The preceding Eq. (10), and Eq. (11) represent ordinal scale. For using DEA, novel methods proposed to transform ordinal scale into cardinal scale [29]. The proposed study uses the following equations to transform ordinal scale into interval scale:

$$\boldsymbol{X_i} \in [\boldsymbol{\delta u^{m-i}}, \boldsymbol{u^{1-i}}];\ \boldsymbol{i = 1, \cdots, m}\ ;\ \boldsymbol{\delta \leq u^{1-m}} \quad , \quad (12)$$

$$\boldsymbol{Y_j} \in [\boldsymbol{\delta u^{n-j}}, \boldsymbol{u^{1-j}}];\ \boldsymbol{j = 1, \cdots, n}\ ;\ \boldsymbol{\delta \leq u^{1-n}} \quad , \quad (13)$$

where $\mathbf{X_i}$, $\mathbf{Y_j}$ represents the interval scale lower and upper bounds for inputs/outputs, $\boldsymbol{u}$ is a parameter indicates the preference intensity given by decision makers and must be greater than 1. $\boldsymbol{\delta}$ is a ratio parameter indicates by decision makers, and $\boldsymbol{i}, \boldsymbol{j}$ represents the ordinal scale of DEMATEL final ranking.

Step 9: The weight restrictions to solve AR-DEA methodology

The final output from the proposed Eq. (12), Eq. (13) presents the absolute number for interval scale of lower and upper bounds for the input/output weight priorities. In addition, the use of interval scale for weights substitutes the linear programming methods [29]. Unlike [2] AR without weight restrictions, and linear programming method [29], the proposed final type of AR is introduced in form. (14). Such that the weight restriction AR is added and modeled as follows:

$$
\begin{aligned}
&E_{0=max \sum_{j=1}^{s} wy_j \, y_{j0}} \ , \\
&s.t \ \sum_{i=1}^{m} wx_i \, x_{i0} \ , \\
&\sum_{j=1}^{s} wy_j \, y_{jz} - \sum_{i=1}^{m} wx_i \, x_{iz} \le 1 \, , \forall_z \ , \qquad (14) \\
&\partial_i \le wx_i \le \gamma_i, \qquad \forall_i, \\
&\beta_j \le wy_j \le \omega_j, \qquad \forall_i,
\end{aligned}
$$

where $\mathrm{wx_i}$ is the weight for input, $\mathrm{wy_j}$ is the weight of output, $\partial_\mathrm{i}, \mathrm{\gamma_i}, \mathrm{\beta}, \mathrm{\omega_j}$ are user specified constants. The weight restrictions a raise some challenges such as problem may not be solves, relative efficiency may not be computed. So [30] proposes to multiply constants of restricts A and B as follows in form (15):

$$
\begin{aligned}
&E_{0=max \sum_{j=1}^{s} wy_j \, y_{j0}} \ , \\
&s.t \ \sum_{i=1}^{m} wx_i \, x_{i0} \ , \\
&\sum_{j=1}^{s} wy_j \, y_{jz} - \sum_{i=1}^{m} wx_i \, x_{iz} \le 1 \, , \forall_z \ , \qquad (15) \\
&\partial_i A \le wx_i \le \gamma_i A, \qquad \forall_i, \\
&\beta_j B \le wy_j \le \omega_j B, \qquad \forall_i,
\end{aligned}
$$

4. The Proposed hybrid methodology

The environment of decision making is surrounded with vague, impression, uncertainty, incomplete information, and non-compensatory. The integrated methodology of decision maker's judgments of DEMATEL and AR-DEA is modeled and summarized in the Fig.2. The steps of the proposed study have been mentioned in details in the previous two sections and will be summarized in Fig.3

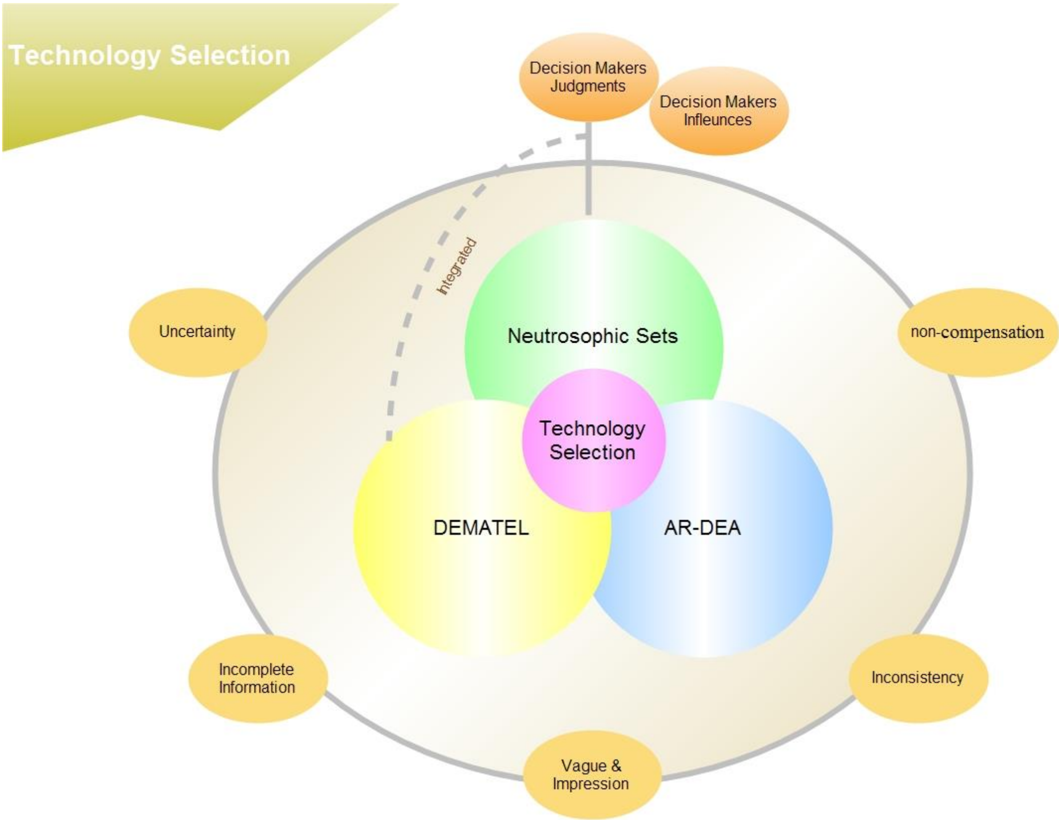

Figure 2. The hybrid methodology of neutrosophic DEMATEL with AR-DEA

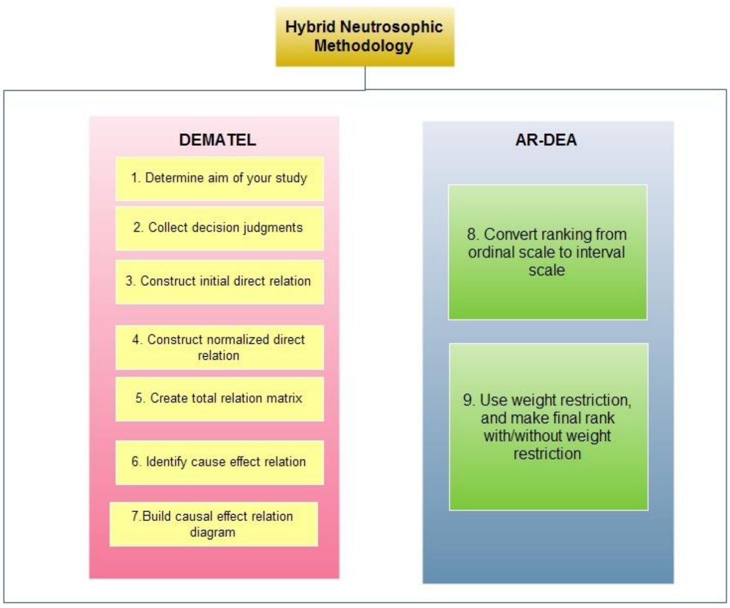

Figure 3. Steps for the proposed hybrid methodology

5. A case study for the proposed hybrid methodology

The proposed hybrid methodology is applied in a wide range of technology selection in Egypt. Egypt is going towards a huge information technology revolution and digital transformation on the practices for many sector of the Egyptian state. The technology revolution contains several axes, including recent developments in information and communications technology. The digital transformation revolution is including the fifth generation of communications, artificial intelligence, and cloud computing. Hence, the current decision makers faces a huge challenges for selecting the most appropriate and efficient technology that will cause a direct influence on the Egyptian state. Hence, we used to apply the proposed hybrid methodology of neutrosophic DEMTAL and AR-DEA. A standard input and output parameters are used in [1, 2]. We consider cost as input, while consider repeatability, load, capacity, velocity, and amount of know-how transfer as outputs for technology selection as mentioned in table 2.

Table 2. The description for the main criterions for technology selection

Criteria	Type	Symbol	Description
Cost	Input	X_1	The disbursement correlated with technology life cycle of introduction, growth, maturity, and decline [31].
Repeatability	Output	Y_1	The degree of closeness of the convention between outcomes under same measurements and conditions [1].
Load Capacity	Output	Y_2	The maximum load for intended property to achieve to the intended expectations with a given distinct amount of weight [32].
Know- how amount transfer	Output	Y_3	The use of distinct technology in a way to operate in such an efficient and effective manner [2].

Step 1: Determine decision makers experts whom are the actual input paramter for the hybird propsed methodology.

Step 2: The decision maker judgements are collected and scaled by the neutrosophic scale mentioned in table 1.

Step 3: Obtain the intial direct relation matrix. The aggregatd paire-wise comparison matrix is obtained by applying Eq.(1) and formed in (2) as depicated in table 3. Apply the score function on the aggregated pair-wise comparison matrix mentioned in Eq.(3) to change the neutrosophic scale to crisp values as mentioned in table 4.

Step 4: Construct th normaized direct matrix by apply Eq.(4) and Eq.(5). The results are mentioned table 5.

Step 5*:* The total relation matrix is computed by the useof Eq.(6) and mentioned in table 6

Step 6: The cause effect relation is presented by the detection of total matrix relation T by the use of Eq.(7), Eq. (8), Eq(9). The resuls of cause effect relation in table 7. According to table 7 the priotorize in importance are Y_1, Y_2, and Y_3, and the less important are Y_3, Y_2, and Y_1.

Step 7: The cause effect diagram is denoted as ($R_i + C_j$) horizontally, and ($R_i - C_j$) vertically ,and illustrated in Fig 4.

Step 8: The ranking from the previous step is Transformed by the use of Eq. (12), Eq. (13) from ordinal scale to interval scale as mentioned in table 8.

Step 9: Considering the DMUs possible scenarios, the use of weight restriction for efficiency is to solve the hybrid neutrosophic AR-DEA methodology. To focus on the importance of the proposed study, ranking computed with/without weight restrictions and results mentioned in table 9. The without weight restriction is computed from [6], and with weight restriction computed according to Eq. (15). Indeed, a difference between $rank_1$, and $rank_2$ notified which lead to the great important for the proposed method as mentioned in Fig.5. By the way, the increase of the amount of parameters in the proposed demonstrates the influence of decision makers than other traditional methods.

Table 3. The initial aggregated pairwise comparison matrix for decision maker's experts

Criteria	Y_1	Y_2	Y_3
Y_1	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 5,6,7\rangle;0.70,0.25,0.30\rangle$
Y_2	$1/\langle\langle 2,3,4\rangle;0.30,0.75,0.70\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$	$\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$
Y_3	$1/\langle\langle 5,6,7\rangle;0.70,0.25,0.430\rangle$	$1/\langle\langle 1,2,3\rangle;0.40,0.65,0.60\rangle$	$\langle\langle 1,1,1\rangle;0.50,0.50,0.50\rangle$

Table 4. The crisp values for initial aggregated pairwise comparison matrix

Criteria	Y_1	Y_2	Y_3
Y_1	1	1.855	2.101
Y_2	0.539	1	1.388
Y_3	0.475	0.720	1

Table 5. The normalized direct matrix

Criteria	Y_1	Y_2	Y_3
Y_1	0.20175	0.374272	0.423978
Y_2	0.108752	0.20175	0.280204
Y_3	0.096003	0.145262	0.20175

Table 6. The total relation matrix

Criteria	Y_1	Y_2	Y_3
Y_1	0.512384	0.913638	1.123984
Y_2	0.288305	0.512387	0.684009
Y_3	0.234351	0.385095	0.512388

Table 7. The cause effect relation of total relation

Rows / *Columns*	Ri	Cj	$R_i + C_j$	$R_i - C_j$	Rank
1	2.550	1.035	3.585046	1.514966	1
2	1.484	1.811	3.29582	-0.32642	3
3	1.131	2.320	3.452215	-1.18855	2

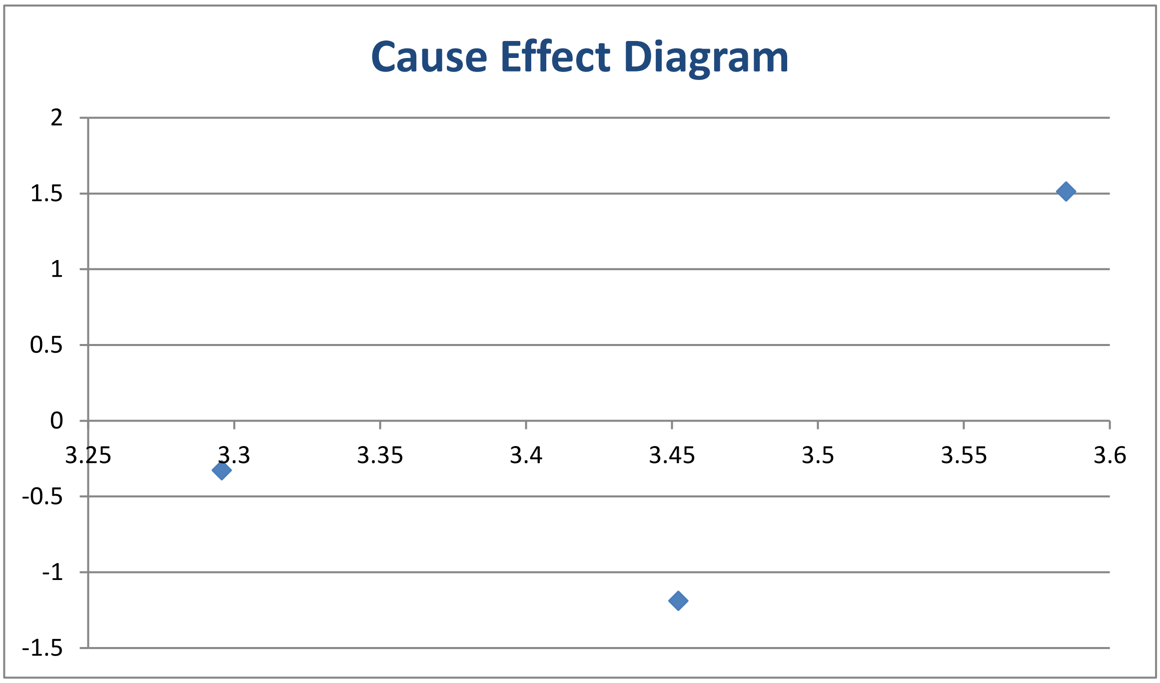

Figure 4. The cause effect diagram

Table 8. The transformation of ordinal scale to interval scale for U_r

Outputs	**Ordinal Scale**	**Lower bound of output weight**	**Upper bound of output weight**
U_1	1	0.22	1
U_2	3	0.1	0.44
U_3	2	0.15	0.66

Table 9. Efficiency score with consideration of with/without weight restrictions

DMU	**Without weight restriction**	**Rank₁**	**With weight restriction**	**Rank₂**
1	1.00	1	1.00	1
2	0.731	3	0.664	3
3	0.881	2	0.748	2
4	0.730	4	0.544	5
5	0.650	5	0.530	4

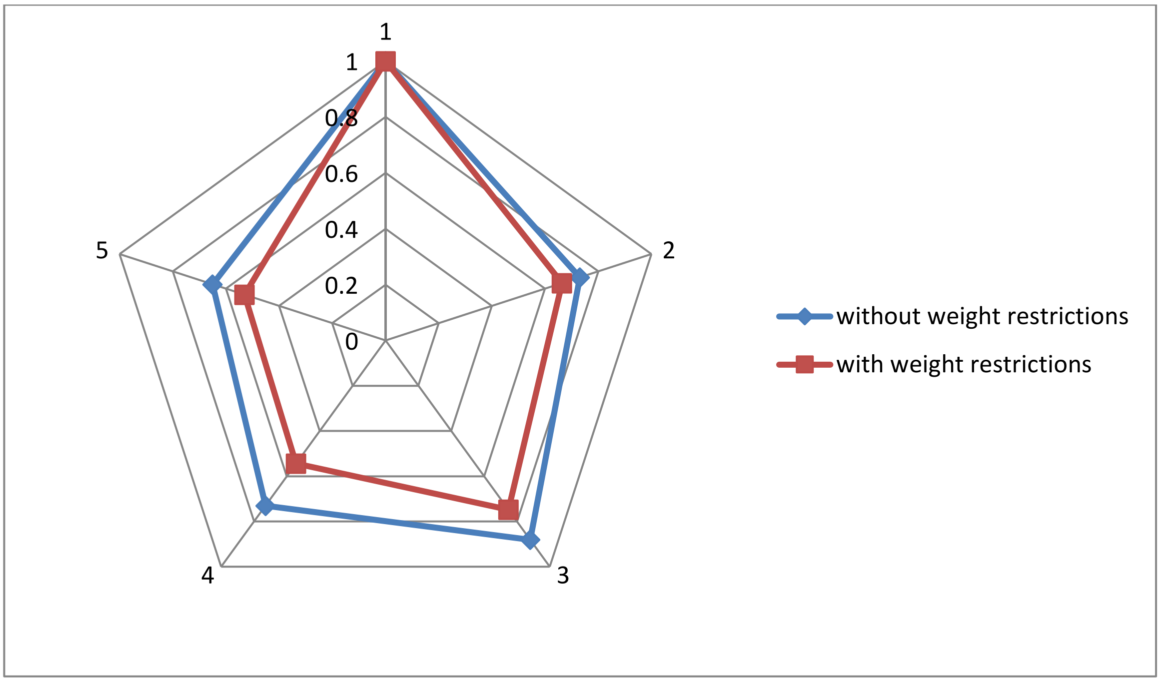

Figure 5. The ranking with/without weight restrictions

6. Conclusion

In this study, a hybrid neutrosophic DEMATEL with AR-DEA for technology selection is proposed. First, the DEMATEL aggregate the decision judgments in conditions of non-compensation, uncertainty, and incomplete information by the use of neutrosophic scale. The DEMATEL detect positive and negative regions in the form of cause effect relation, and introduce ranking for relations of inputs and outputs effects for technology selection process. Second the use of AR-DEA evaluate the efficiency for DMUs according to weight restrictions of AR to involve many influences of decision makers, rather than the traditional method of non-considering weight restrictions. A case study is applied on technology revolution and digital transformation in EGYPT that demonstrates the importance for the proposed study. For future trends, we can extend study by use of TOPSIS and MUTLIMOORA methods and make comparisons among ranking results.

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