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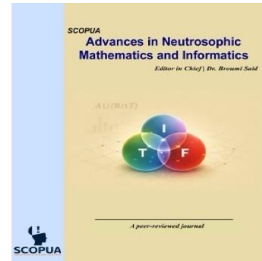

Integrated Neutrosophic DoE & MCDM approach in Sustainable Technology Selection

Rajkumar S [1,2*], P Sathya [1,2], Theeba A [1,2]

[1]Department of Mathematics, Arul Anandar College (Autonomous), Karumathur, Affiliated to Madurai Kamaraj University, India

[2]Department of Mathematics, G.T. N Arts College (Autonomous), Dindigul, India

* Corresponding Email: rajkumardgl91@gmail.com

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ABSTRACT

The decision making on sustainable technology selection is an intricate process which involves multiple conflicting criteria, uncertain data with indeterminate expert judgements. This study proposes a hybrid neutrosophic decision making approach blending the dynamics of Design of experiments (DoE) and multi criteria decision making (MCDM) method to enhance the reliability of selection process. The newly developed hybrid method employs the method of DoE to evaluate the performance of alternative technologies under diverse operational conditions. The experimental outcomes are expressed using linguistic variables to address vagueness, indeterminacy and inconsistency inherited in real-world assessments. The subsequent representations of linguistic variables using single valued neutrosophic numbers facilitate in designing an aggregate input neutrosophic decision matrix to the next phase of MCDM ranking. The hybrid method is applied to a hypothesized decision making problem of sustainable technology selection considering core criteria and factors contributing to operational efficiency. The results demonstrate that the integrated decision approach of DoE with TOPSIS & VIKOR provides more consistent and reliable ranking results contributing to resilient decision making systems.

Keywords*:*Single valued neutrosophic number; Design of Experiments; TOPSIS; VIKOR

1. Introduction

Decision-making Smarandache [1] introduced the theory of neutrosophy as three valued logic of the form (T, I, F) with truth, indeterminacy and falsity representations. Neutrosophic driven decision making approaches are developed to evolve more comprehensive process of finding solutions to complex problems. The theory of neutrosophy is discussed with other mathematical entities, to mention a few, Broumi et al. [2] discoursed rough neutrosophic sets. Dhar and Broumi [3] developed square neutrosophic fuzzy matrices. Dhar [4,5] conceptualized neutrosophic soft block matrices. Dhar [6] investigates properties and applications of K-idempotent neutrosophic fuzzy matrices. Furthermore, neutrosophic theory is also integrated with the field of statistics to handle inconsistent data. Researchers have developed neutrosophic statistical models combining the principles of neutrosophic to statistical modelling. To mention a few, Kumar et al [7] employed neutrosophic graeco-latin square design in performing neutrosophic analysis of experimental data. Khan et al [8] designed S-control chart for neutrosophic data and applied to manufacturing industry. Aslam et al [9] discussed neutrosophic statistical interval method for exponential and pareto distributions. Azeem [10] described neutrosophic based sampling design. Fatima et al [11] elicited the applications of neutrosophic statistics in data analysis. AlAita and Asla [12] discoursed on analysis of covariance with neutrosophic representations. Riaz et al, Afzal & Aslam [13,14] applied neutrospohic statistics to handle medical data. Kumar and George [15] explained the dynamics of neutrosophic multifactor analysis. Pavithra et al, Martin et al, Aleeswari et al [16,17,18] have presented the applications of neutrosphic inferential statistical methods in real world problems.

The aforementioned developments and applications of neutrosophic statistics lay a clear picture of neutrosophic efficiency in data handling. However on profound analysis, researchers have developed many neutrosophic integrated Design of

Experiment (DoE) models considering factorial design and randomized designs. The statistical approach of DoE is highly structured and proactive in nature. This approach is applied to effectively evaluate the performance of multiple factors and their influences under controlled conditions. Neutrosphic DoE models enhance the efficiency in drawing inferences from incomplete and indeterminate data.

Besides, neutrospohic statistics, the mathematical structures are also discussed with neutrosophic principles which have resulted in optimal decision models. To mention a few significant works, Angammal et al [19] formulated a multi attribute neutrosophic optimization techniques for optimal crop selection. Ashika et al [20] discussed the application of enhanced neutrosophic set in breast cancer prediction. Sudha and Martin [21] demonstrated the applications of different neutrosophic methods in logistics selection. Priya and Martin [22] framed a novel model of neutrosophic sociogram based neutrosophic cognitive maps. Martin et al [23] designed a decision model using concentric neutrosophic hypergraphs in medical diagnosis. Neutrosophic optimization techniques are also explored. Neutrosophic algebra is applied in evolving decision making models to determine solutions to the challenges in the field of education, healthcare, green supply chain management and other related domains. Neutrosophic multi criteria decision making methods are also evolved to choose the optimal alternatives subjected to multiple criteria.

The neutrosophic DoE and multi criteria decision making models handle multiple factors. The neutrosophic DoE model studies the interactions among the multiple factors of a decision making problem, however, they do not facilitate ranking of alternatives. On other hand, the MCDM ranks only the alternatives based on the given data and lacks opportunities to study the interactions among the factors. The shortcomings of these two models shall be bridged by developing an integrated neutrosophic model of DoE and MCDM. The proposed unified model is demonstrated with a hypothetical decision making scenario of sustainable technology selection. The MCDM method of TOPSIS & VIKOR is chosen. The other contents are structured as follows. The preliminaries are presented in section 2. The methodology of the integrated approach is described in section 3. The decision making problem of sustainable technology selection is presented in section 4. The results of the proposed method are further examined through a sensitivity analysis presented in section 5 to evaluate the robustness and consistency of the ranking outcomes. The last section summarizes the work with industrial implications and future directions.

2. Preliminaries

This section presents the fundamental concepts required for model development.

2.1 Neutrosophic set [24]

A neutrosophic set B on universal set X is basically characterized as a three valued logic with truth, indeterminacy and falsity functions, where each $T_B(x)$, $I_B(x)$, $F_B(x)$ is defined from $X \to]0^-, 1^+[$ such that $0 \leq T_B(x) + I_B(x) + F_B(x) \leq 3$

2.2 Single valued neutrosophic number [24]

The single valued neutrosophic number say B is also referred as neutrosophic set with same characterization in which $B=\{\langle x, T_B(x), I_B(x), F_B(x): x\in X \rangle$

2.3 Neutrosophic Operations [24]

Let $B_1=\langle T_1, I_1, F_1\rangle$ and $B_2=\langle T_2, I_2, F_2\rangle$ and $\lambda>0$ be any real number. The fundamental operations are defined as follows:

- Addition $(B_1 \oplus B_2)$: $B_1 \oplus B_2=\langle T_1+T_2-T_1T_2, I_1I_2, F_1F_2 \rangle$
- Multiplication$(B_1 \otimes B_2)$: $B_1 \otimes B_2=\langle T_1T_2, I_1+I_2-I_1I_2, F_1+F_2-F_1F_2 \rangle$
- Scalar Multiplication(βA_1): $\beta A_1=\langle 1-(1-T_1)^\beta, I_1^\beta, F_1^\beta \rangle$
- Scalar Multiplication$\left(B_1^\beta\right)$: $B_1^\beta=\langle T_1^\beta, 1-(1-I_1)^\beta, 1-(1-F_1)^\beta \rangle$

2.4 Score value [24]

Let $B=\langle T, I, F\rangle$ be a single valued neutrosophic number, the score value S(A) is

$$S(A)=\frac{(2+T-I-F)}{3}$$

Where $S(A)\in[-1,1]$

2.5 Linguistic Variable [25]

A variable assuming linguistic values is called as linguistic variable. For example, to describe the performance of an equipment, linguistic variables such as‘ low’, ‘medium’ and ‘high’ shall be used to describe the working competence of the equipment.

3. Methodology of Integrated Framework

This section presents the detailed procedure of the integrated approach. This method consists of two phases in which the first phase employs the method of neutrosophic DoE and the second phase applies MCDM to rank the alternatives.

Step 1: Problem Definition

The decision making problem is first well defined with alternatives and criteria. Let the alternatives be represented using $A_i,\ i = 1,2,...,m$, criteria as $C_j,\ j = 1,2,...,n$. The criterion weights are represented using w_j such that $\sum_{j=1}^{n} w_j = 1, w_j > 0$. The criteria are classified as benefit and cost say J_b and J_c respectively.

Step 2: Design of Experiments (DoE)

The control factors in a structured experimental design are evaluated to determine their influences over the performance of the alternatives. The data obtained is scientific in nature. The factors are represented using $F_p,\ p = 1,2,...,P$. The experimental runs are denoted using E_k, where $k = 1,2,...,K$. The observations for all alternatives and criteria are recorded from each of the experimental runs.

Step 3: Linguistic Representation

The linguistic variables are used to express the expert's judgements. These variables are quantified using single valued neutrosophic numbers of the form

$$\tilde{x}_{ijk} = (T_{ijk}, I_{ijk}, F_{ijk}),\ T_{ijk}, I_{ijk}, F_{ijk} \in [0,1], 0 \leq T + I + F \leq 3$$

Step 4: Neutrosophic Aggregation of DoE Output

The outputs obtained from each experimental runs are aggregated into a single neutrosophic value using

$$\tilde{x}_{ij} = \frac{1}{K}\sum_{k=1}^{K} \tilde{x}_{ijk} = \left(\bar{T}_{ij}, \bar{I}_{ij}, \bar{F}_{ij}\right) \tag{1}$$

The neutrosophic decision matrix thus obtained is of the form

$$\tilde{X} = [\tilde{x}_{ij}]_{m\times n}$$

Step 5: Normalization of Neutrosophic Data

The neutrosophic values in the decision matrix are normalized using (2) and (3)

For Benefit Criteria:

$$\tilde{r}_{ij} = \left(\frac{T_{ij}}{\max_i T_{ij}}, \frac{I_{ij}}{\max_i I_{ij}}, \frac{\min_i F_{ij}}{F_{ij}}\right) \tag{2}$$

For Cost Criteria:

$$\tilde{r}_{ij} = \left(\frac{\min_i T_{ij}}{T_{ij}}, \frac{I_{ij}}{\max_i I_{ij}}, \frac{F_{ij}}{\max_i F_{ij}}\right) \tag{3}$$

Step 6: Weighted Neutrosophic Decision Matrix

The weighted normalized neutrosophic decision matrix is obtained by multiplying the criterion weights with the normalized decision matrix.

$$\tilde{v}_{ij} = w_j \cdot \tilde{r}_{ij} = (w_j T_{ij},\ w_j I_{ij},\ w_j F_{ij}) \tag{4}$$

This weighted normalized neutrosophic matrix serves as the input for the next phase of MCDM ranking.

Neutrosophic TOPSIS Method

Step 7: Determine Ideal Solutions

The method of TOPSIS identifies the best (ideal) $\tilde{v}_j^+$ and worst (anti-ideal) $\tilde{v}_j^-$ alternatives based on neutrosophic values.

$$\tilde{v}_j^+ = (\max_i T_{ij},\ \min_i I_{ij},\ \min_i F_{ij})$$

$$\tilde{v}_j^- = (\min_i T_{ij},\ \max_i I_{ij},\ \max_i F_{ij}) \tag{5}$$

Step 8: Distance Measures

The distance of each alternative from the ideal and anti-ideal solutions is computed.

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(T_a - T_b)^2 + (I_a - I_b)^2 + (F_a - F_b)^2]}$$

$$D_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+)$$

$$D_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) \tag{6}$$

Step 9: Closeness Coefficient

The closeness coefficient is used to determine the best alternative which is the one closest to the ideal solution and farthest from the anti-ideal solution.

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{7}$$

Neutrosophic VIKOR Method

Step 10: Computation of Best and Worst Values

The best and worst values are determined using (8)

$$\tilde{f}_j^* = (maxT_{ij},\ minI_{ij},\ minF_{ij})$$
$$\tilde{f}_j^- = (minT_{ij},\ maxI_{ij},\ maxF_{ij}) \tag{8}$$

Step 11: Calculation of Utility and Regret Measures

The alternatives are evaluated using group utility (S) and individual regret (R). The score value of neutrosophic data is determined using (9)

$$S(\tilde{x}) = T - I - F$$
$$S(\tilde{x}) = T - I - F$$

Also,

$$\Delta_{ij} = \frac{S(\tilde{f}_j^*) - S(\tilde{v}_{ij})}{S(\tilde{f}_j^*) - S(\tilde{f}_j^-)}$$
$$S_i = \sum_{j=1}^{n} w_j\, \Delta_{ij}$$
$$R_i = \max_j (w_j \Delta_{ij}) \tag{9}$$

Step 12: Computation of VIKOR Index

The VIKOR index is calculated using (10)

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + (1 - v) \cdot \frac{R_i - R^*}{R^- - R^*} \tag{10}$$

where:

- $v = 0.5$ (generally)
- $S^* = minS_i,\ S^- = maxS_i$
- $R^* = minR_i,\ R^- = maxR_i$

Step 13: Ranking of the alternatives using combined score values

The score values obtained using TOPSIS and VIKOR is combined using

$$\gamma\, CCi + (1 - \gamma)(1 - Qi), \text{ where } \gamma \in [0,1] \tag{11}$$

The alternatives are ranked based on the combined score values. The procedure of the proposed integrated approach is presented as a flow chart in Fig. 1

Figure 1: Flowchart of Integrated DoE & MCDM Method

4. Decision Making on Prioritizing Sustainable Technology

The method presented in section 2 is validated with a hypothetical decision making scenario of prioritizing sustainable technology. Let us consider the alternatives of five technology, say T1, T2, T3,T4,T5. The criteria considered for ranking these alternatives are presented in Table 1.

Table 1: Description of Criteria

Criteria	Symbol	Type	Weights (wj)
Cost	C1	Minimize	0.3
Efficiency	C2	Maximize	0.5
Environmental Impact	C3	Minimize	0.2

In the above table, the criteria are classified as benefit and cost and the criterion weights are assumed such that $\sum_{j=1}^{n} w_j = 1$. $J_b = \{C_2\}$ and $J_c = \{C_1, C_3\}$

Let us consider two factors say F1 and F2 affecting performance:

- F_1: Installation Quality (Low, High)
- F_2: Maintenance Level (Low, High)

The Full Factorial design is presented in Table 2.

Table 2: Full Factorial Design

Run	F_1	F_2
R_1	Low	Low
R_2	Low	High
R_3	High	Low
R_4	High	High

For simplicity, let us consider the assumed values of T1 – T5 under each run as presented in Table 3.

Table 3: Outputs of Experimental Runs

High				High			
Run	**Cost**	**Efficiency**	**Impact**	**Run**	**Cost**	**Efficiency**	**Impact**
R1	High	Medium	High	R1	Medium	Medium	Medium
R2	High	High	High	R2	Medium	High	Medium
R3	Medium	High	Medium	R3	Medium	Medium	Medium
R4	Medium	Very High	Medium	R4	Medium	High	Medium
T3				**T4**			
Run	**Cost**	**Efficiency**	**Impact**	**Run**	**Cost**	**Efficiency**	**Impact**
R1	High	High	Medium	R1	High	High	Medium
R2	High	Very High	Medium	R2	High	Very High	Medium
R3	Medium	High	Medium	R3	Medium	High	Medium
R4	High	Very High	High	R4	High	Very High	High
T5							
Run	**Cost**	**Efficiency**	**Impact**				
R1	High	High	Medium				
R2	High	Very High	Medium				
R3	Medium	High	High				
R4	Medium	Very High	Medium				

The above mentioned linguistic variables are quantified as mentioned in Table 4.

Table 4: Neutrosophic Quantificatns of Linguisitc Variables

Linguistic	**SVNN**
Low	(0.3, 0.5, 0.7)
Medium	(0.5, 0.4, 0.5)
High	(0.7, 0.3, 0.3)
Very High	(0.9, 0.1, 0.1)

The linguistic variables are quantified using single valued neutrosophic numbers. The aggregated values are obtained using (1). The final weighted normalized matrix obtained using (4) is

Alt	**C1**	**C2**	**C3**
T1	(0.250, 0.257, 0.225)	(0.438, 0.459, 0.375)	(0.167, 0.171, 0.150)
T2	(0.300, 0.225, 0.180)	(0.375, 0.500, 0.500)	(0.200, 0.150, 0.120)
T3	(0.214, 0.300, 0.300)	(0.500, 0.334, 0.250)	(0.167, 0.200, 0.150)
T4	(0.250, 0.257, 0.225)	(0.469, 0.417, 0.313)	(0.182, 0.171, 0.133)
T5	(0.231, 0.300, 0.257)	(0.488, 0.334, 0.313)	(0.167, 0.200, 0.150)

Let us apply neutrosophic TOPSIS and VIKOR and determine the score values. Using step 7-9 the score values of each alternatives are obtained and presented in Table 5.

Table 5: Neutrosphic Score Values

Alt	**(D_i^+)**	**(D_i^-)**	**CCi**
T1	0.150	0.165	0.524
T2	0.209	0.150	0.418
T3	0.150	0.209	0.582
T4	0.080	0.190	**0.704**
T5	0.095	0.180	0.655

The method of Neutrosophic VIKOR is applied and the score values are obtained using steps 10 -12 and are presented in Table 6.

Table 6: Neutrospohic VIKOR Scores

Alt	**Si**	**Ri**	**Qi**
T1	0.420	0.250	0.567

T2	0.500	0.300	1.000
T3	0.350	0.214	0.358
T4	0.200	0.150	**0.000**
T5	0.250	0.180	0.183

The combined score values obtained using step 13 and the rankings of the alternatives are presented in Table 7.

Table 7: Combined Ranking of the Alternatives

T1	T2	T3	T4	T5
0.479	0.209	0.612	0.852	0.736
4	5	3	1	2

5. Sensitive Analysis

The ranking results and the score values of the alternatives are presented in Fig. 2

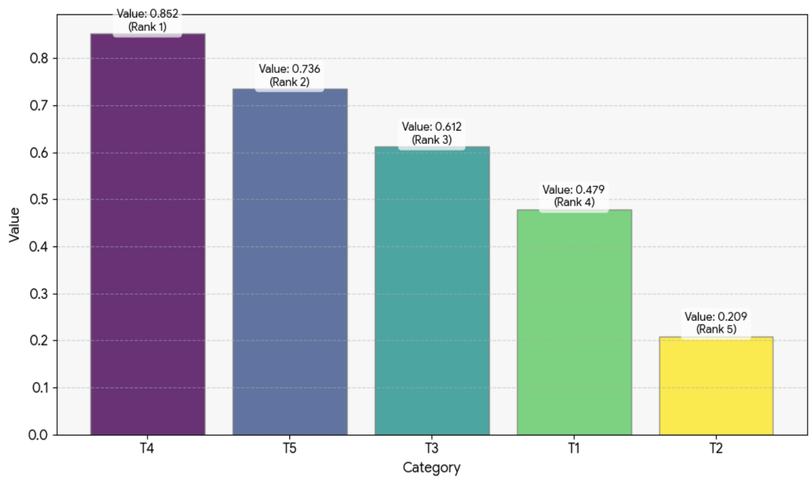

Figure 2: Ranking Results of the Alternatives

From the figure 2, the ranking results of the alternatives are very evident. The combined score values facilitate the decision makers in determining the most sustainable technology. This proposed method integrates the design of experiment approach in determining he aggregate neutrosophic matrix. Also, the ranking of the alternatives is more consistent as it is based on combined score values of TOPSIS & VIKOR.

The ranking results are sensitively analysed for various values of γ and are presented in Table 8.

Table 8: Combined score values for various values of γ

Alternatives	γ=0.25	γ=0.45	γ=0.65	γ=0.85
T1	0.45575	0.47395	0.49215	0.51035
T2	0.1045	0.1881	0.2717	0.3553
T3	0.627	0.615	0.603	0.591
T4	0.926	0.8668	0.8076	0.7484
T5	0.7765	0.7441	0.7117	0.6793

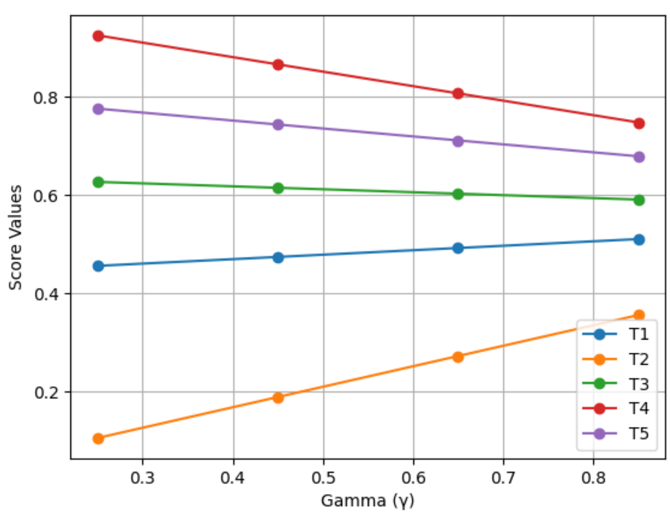

Figure 3: Sensitivity analysis of Score values wrt to γ

From the score values presented in Table 8 & Fig.3, the following inferences on ranking of the alternatives are obtained.The alternative T4 consistently occupies first position across all the values of γ. T5 maintains the second position with stability and reliability. The ranking of T3 remains in the third position with mild decreasing trend. The alternatives T1 and T2 occupies fourth and fifth positions constantly for all values of γ. The consistency of ranking is demonstrated using various values of γ. The integrated approach is reliable as the decision making matrix is obtained using design of experiments. In a general MCDM, the decision making matrix is constructed based on expert's opinion which are purely judgemental. However in the proposed method, the decision matrix is empirical.

5. Conclusion

This research work proposes an integrated neutrosophic decision making approach combining the statistical method of design of experiment with multi criteria decision making method of TOPSIS & VIKOR. The ranking of the alternatives is based on the computations of combined score values. The decision making matrix employed in ranking is more empirical rather than judgemental. The proposed hybrid approach is validated using a hypothetical decision making scenario of sustainable technology selection. The reliability of the results is evident from the sensitivity analysis. This kind of blended decision making model shall be applied to diverse industrial oriented decision making scenario which involves conflicting multiple factors. As the manufacturing sectors face several challenges of optimal decision making, this proposed hybrid approach shall be applied to tackle such difficult situations. This integrated approach shall be extended using other kinds of neutrosophic numbers catering to the needs of data representation.

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Author(s) Bio / Authors' Note

Mr. Rajkumar S is working as an Assistant Professor in G.T.N.Arts College, Dindigul, India. He is presently pursuing research in the field of neutrosophy. His areas of research are Decision Making, Operations Research,Quantum Computing. He has presented his research works in several National and International conferences. Email: rajkumardgl91@gmail.com

Ms. Theeba A is working as an Assistant Professor in G.T.N.Arts College, Dindigul, India. She is presently pursuing research in the field of Operationa Research. Her areas of research are Optimization, Neutrosophic Modelling,Quantum Computing. She has presented her research works in several National and International conferences. Email: theebajoe@gmail.com

Ms. Sathya S is working as an Assistant Professor in G.T.N.Arts College, Dindigul, India. She is presently pursuing research in the field of Plithogeny. Her areas of research are Mathematical Modelling,Quantum Computing and Decision Making. She has presented her research works in several National and International conferences. Email: prathisath@gmail.com