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Neutrosophic BWM-TOPSIS Strategy under SVNS Environment

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Abstract: Decision making under an uncertain environment is a critical task. In this article, we develop a Multi Attribute Decision Making (MADM) model using BWM and Neutrosophic-TOPSIS under Single Valued Neutrosophic Set (SVNS) environment. In developed model, BWM is utilized to find the weights of the attributes those are selected by a group of experts, and the Neutrosophic-TOPSIS is utilized to rank the alternatives.

Keywords: Decision Making; BWM; Neutrosophic-TOPSIS; Uncertainty; SVNS.

1. Introduction:

In Multi- Attribute Decision Making (MADM) decision-maker determines the best choice form a set of possible alternatives subject to multiple conflicting criteria. A strategic approach requires to be performed to deal with MADM involving uncertainty. In the MADM algorithm, a decision matrix is formed by the decision-maker to find a ranking of the alternatives.

Fuzzy set theory, proposed by Zadeh [1], has been very useful in dealing with MADM problems involving uncertainty. Decision making is a successful field of study in the fields of Medical Science, Operations Research, Data Mining, Management Science, etc. In the present era there are various popular methods like AHP [2], TODIM [3, 4], VIKOR [5, 6, 7], TOPSIS [8, 9, 10], MULTIMOORA [11], GRA [12], Cross entropy measure [13], DEMATEL [14], Subsethood measure [15], aggregation operators [16], etc. to solve the MADM under uncertain environment. Among those techniques, TOPSIS received a lot of attention in the past decade and many mathematicians studied the method for solving many MADM problems in various situations. In 2011, Pramanik and Mukhopadhyay [17] presented the Multi Attribute Group Decision Making (MAGDM approach to select the teachers based on the Grey Relational Analysis (GRA) under Intuitionistic Fuzzy Set (IFS) environment.

Chen [18] introduced the TOPSIS method in the fuzzy environment and considered the rating value of the alternative and attribute weight in terms of a triangular fuzzy number. In 2009, Boran et al. [19] extended the TOPSIS method for MAGDM under IFS environment to solve the supplier selection problem. In 2010, Ye [20] extended the TOPSIS method with an interval-valued IFS environment. In 2015, Rezaei [21] introduced the Best-Worst Method (BWM). In comparison with the current MADM methods, BWM needs more consistent comparisons, fewer comparison data with more good results. In 2020, Mohammad Javad et al. [22] presented a model of green supplier selection for the steel industry using BWM and fuzzy TOPSIS.

Till now fuzzy MADM and intuitionistic fuzzy MADM problems are studied by many researchers. Presently multiple researchers use uncertainty in the model formulation of different MADM problems. Uncertainty acts as a vital role in MADM difficulties. So neutrosophic sets should be applied in the complex environment involving uncertainty, indeterminacy and inconsistency the MADM method. Since fuzzy and intuitionistic fuzzy MADM difficulties are extensively investigated, but indeterminacy should be included in the MADM difficulties. Smarandache [23] grounded the neutrosophic set to represent the mathematical model of uncertainty, imprecision, and inconsistency. In 2010, Wang et al. [24] presented the notion of single valued neutrosophic set (SVNS). Later on, Biswas et al. [25] studied the entropy based GRA approach for MADM under SVNS environment.

In an MADM algorithm, weights of the attributes play an essential role in ranking the alternatives. In the proposed MADM algorithm, we apply BWM to find the weights of the criteria and the Neutrosophic-TOPSIS method to rank the alternatives.

The remaining paper has been split into several sections. Section 2 is on the preliminaries and the definitions. Section 3 is on neutrosophic BWM-TOPSIS by using hybrid score-accuracy values under SVNS environment. Section 4 deals with the validation of our proposed model. In this section, we consider an example to verify our proposed MADM model. Section 5 presents concluding remarks of the work and future scope research.

2. Preliminaries and Definitions:

The notion of Neutrosophic Set was grounded by Smarandache [23] in 1998. Afterwards, Wang et al. [24] introduced the concept of Single Valued Neutrosophic Set (SVNS) to deal with the events having indeterminate, incomplete information.

An SVNS W over a fixed set Ω is defined as follows:

$$W = \{(q, T_W(q), I_W(q), F_W(q)) : q \in \Omega\},$$

where T_W, I_W, F_W are functions from Ω to [0, 1] and so $0 \le T_W(q) + I_W(q) + F_W(q) \le 3$. For any SVNS W over a fixed set Ω, the triplet $(T_W(q), I_W(q), F_W(q))$ is called a Single Valued Neutrosophic Number (SVNN).

Assume that $W = \{(q, T_W(q), I_W(q), F_W(q)) : q \in \Omega\}$ and $M = \{(q, T_M(q), I_M(q), F_M(q)) : q \in \Omega\}$ be two SVNSs [24] over Ω. Then,

(i) $W^C = \{(q, 1\text{-}T_A(q), 1\text{-}I_A(q), 1\text{-}F_W(q)) : q \in \Omega\}$ is called the complement of W;

(*ii*) $W \subseteq M$ if and only if $T_W(q) \le T_M(x)$, $I_W(q) \ge I_M(q)$, and $F_W(q) \ge F_M(q)$, for all $q \in \Omega$;
(*iii*) $W = M$ if and only if $W \subseteq M$ and $M \supseteq W$;
(*iv*) $W \cup M = \{(q, T_W(q) \vee T_M(q), I_W(q) \wedge I_M(q), F_W(q) \wedge F_M(q)) : q \in \Omega\}$;
(*v*) $W \cap M = \{(q, T_W(q) \wedge T_M(q), I_W(q) \vee I_M(q), F_W(q) \vee F_M(q)) : q \in \Omega\}$.

Score Function:

In 2018, Mondal and Basu [26] proposed a new score function to solve MADM problems under the SVNS environment as follows:
The score function is defined by the following steps:

Step 1: Suppose that O is the origin and N= *(t_n, i_n, f_n), an SVNN, represents a point in three-dimensional* space. Take a translation of that point N to M = (t_m, i_m, f_m), where $t_m = t_n+r$, $i_m = i_n+r$, $f_m = f_n+r$, where r > 0, a real number such f_m never becomes 1 and unique throughout a particular problem. Consider another point M′ = (t_m,- i_m, -f_m), which is the image of (t_m, i_m, f_m), with respect to the x axis as a mirror.

Step 2: Find the score function S_1(M) =Cos (a), where a is the angle between OM and OM′, O is the origin.

Step 3: If the score values $S_1(N_1)$ and $S_1(N_2)$ are same, for two different SVNNs $N_1\,(t_{n_1}, i_{n_1}, f_{n_1})$ and $N_2 = (t_{n_2}, i_{n_2}, f_{n_2})$, determine $N_1^{**} = (t_{n_1}, -i_{n_1}, -\sqrt{f_{n_1}})$ and $N_2^{**} = (t_{n_2}, -i_{n_2}, -\sqrt{f_{n_2}})$ respectively for the corresponding translated points $N_1^{*} = (t_{n_1^*}, i_{n_1^*} f_{n_1^*})$ an $N_2^{*} = (t_{n_1^*}, i_{n_1^*} f_{n_1^*})$,, where $t_{n_1^*} = t_{n_1} + r, f_{n_1^*} = f_{n_1} + r, i_{n_1^*} = i_{n_1} + r$ and $t_{n_2^*} = t_{n_2} + r, f_{n_2^*} = f_{n_2} + r, i_{n_2^*} = i_{n_2} + r$.

Step 4: Find Cos (b) and Cos (c), where b is the angle between ON_1^{*} and ON_1^{**} and c is the angle between ON_2^{*} and ON_2^{**}, O is the origin.

Step 5: The score function $S_2(N_1)$ = Cos(b) and $S_2(N_2)$ = Cos(c).

Example 2.1. Suppose that K_1=(0.4, 0.3, 0.2) be an SVNN. Then, score value of K_1 is s(K_1) = 0.090496 , for r= 0.01.

3. Method

In this section, we describe the BWM and Neutrosophic-TOPSIS strategy. In our MADM algorithm BWM is mainly used to find the weights of the selected attributes and TOPSIS is used for ranking the set of alternatives.

3.1. BWM

In an MADM algorithm, attributes selection by the expert, and calculate the weights of those attributes is the most important and critical task. The Best-Worst Method [21] is the best suitable method to determine the values of the weights for the selected attributes.
The BWM method is stated as follows:

i. Selection of a family of m decision-makers.
ii. Selection of a family of n attributes.
iii. Selection of the best attribute and the worst attribute.
iv. Give preference of the best attribute over all the other attributes based on a scale of 1 to 9. The best-to-others vector shows the preference of the best attribute over all other attributes that can be written as: A_b=(a_{b1}, a_{b2}, ……., a_{bn}), where a_{bi} =the preference of the best attribute b over the attribute i and a_{bb}=1.
v. Assign preference of all the other attributes over the worst attribute based on a scale of 1 to 9. The others-to-worst vector shows the preference of all other attributes over the worst attribute that can be written as: A_w=(a_{1w}, a_{2w}, ……., a_{nw})^T, where a_{iw} =the preference of the attribute i over the worst attribute w and a_{ww}=1.
vi. Determine the optimal weights of all the attributes (w_1, w_2, ……, w_n).

The objective is to find the optimal weights so that the maximum absolute differences for all i are minimized of the $\{|w_b-a_{bi}w_i|, |w_i-a_{iw}w_w|\}$.

The following model is resulted considering the weights non-negativity and summation of weights constraints.

min max $\{|w_b-a_{bi}w_i|, |w_i-a_{iw}w_w|\}$

Such that

$\sum_i w_i = 1$ (1)

$w_i \geq 0$, for all i.

Now, we can be transferred the model (1) to the following linear model:

min C_R

Such that

$|w_b-a_{bi}w_i| \leq C_R$, for all i

$|w_i-a_{iw}w_w| \leq C_R$, for all i (2)

$\sum_i w_i = 1$

$w_i \geq 0$, for all i.

After solving eq. (2), we get the weights (w_1, w_2, ……, w_n) and value of C_R. The value of C_R closer to zero indicates desired consistency.

3.2. TOPSIS

Till now many MADM strategies were developed. Among them TOPSIS is one of the most popular MADM strategy to rank the set of alternatives. Also, the rank of the set of alternatives is the most necessary part of an MADM problem. In this section we describe the TOPSIS method for ranking the alternatives.

First we need to consider a set of alternatives A={W_1, W_2, W_3, …., W_m} with m≥1 and a set of attributes C={A_1, A_2, A_3, ……,A_n} with $n \geq 2$ and choose the weights w_1, w_2, …..,w_n for each attributes A_i, (i=1, 2, 3,.., n} respectively.

Decision-makers provides rating of the alternatives W_j, (j=1, 2, 3,…, m) based on the attributes A_i, (i=1, 2, 3,.., n}, which is represented in term of an SVNN. Assume that rating of j-th attribute with respect to i-th alternative is presented as follows:

$W_j^* = \left(A_i, T_{W_j}(A_i), I_{W_j}(A_i), F_{W_j}(A_i)\right)$, j = 1, 2, ……., m, where $0 \le T_{W_j}(A_i) + I_{W_j}(A_i) + F_{W_j}(A_i) \le 3$.

Here (T_{ji}, I_{ji}, F_{ji}) is denoted as an SVNN. W_j^* , (i = 1, 2, 3,..., n, and j = 1, 2, 3, …, m, where i = no of attributes and j= no of alternatives. Based on rating Therefore, we get the decision matrix:
D*=$(W_{ji}^*)_{m\times n}$
Now, TOPSIS method is summarized as follows:

i. The score-matrix D=$\left(W_{ji}\right)_{m\times n}$ (j=1,2,…,m; i=1,2,….,n) is obtained from the decision matrix D*=$(W_{ji}^*)_{m\times n}$ by using the following described in preliminary section:
i.e., W_{ji} = s1(W_{ji}^*).

ii. Determination of normalized decision matrix N=$(N_{ji})_{m\times n}$
where $N_{ji} = \frac{w_{ji}}{\sqrt{\sum_{j=1}^{m} w_{ji}^2}}$, j=1, 2, 3, …, m; i=1, 2, 3, …, n.

iii. Determine the weighted normalized decision matrix V=$(V_{ji})_{m\times n}$
where V_{ji}= w_i*N_{ji}, j=1, 2, 3, …, m; i=1, 2, 3, …, n.

iv. Determine the Neutrosophic Positive Ideal Solution (NPIS) and Neutrosophic Negative Ideal Solution (NNIS).
NPIS $I^+ = \{v_1^+, v_2^+, v_3^+, \ldots . v_n^+\}$, where $v_i^+ = max\, V_{ji}$, i=1, 2, 3, …, n;
NNIS $I^- = \{v_1^-, v_2^-, v_3^-, \ldots . v_n^-\}$, where $v_i^- = min\, V_{ji}$, i=1, 2, 3, …, n.

v. Determine the distance of each alternative from NPIS and NNIS using the following formula,

$S_j^+ = \sqrt{\sum_{i=1}^{n}(V_{ji} - V_i^+)^2}$, j = 1, 2, …. , m

$S_j^- = \sqrt{\sum_{i=1}^{n}(V_{ji} - V_i^-)^2}$, j = 1, 2, …. , m

vi. Calculate the performance score of each alternative by using the formula
P_j=$\frac{S_j^-}{S_j^- + S_j^+}$

vii. Put the performance score in ascending order and rank the alternatives.

4. Validation of the Proposed BMW-TOPSIS Strategy

In this section we present a numerical example to validate the developed MADM model.

Example 4.1. "Selection of Suitable Flat for a Customer".

Suppose a customer wants to buy a Flat from a set of available alternatives/Flats. The quality of the flat is very important for the customer and it is dependent on the price that is why it is a variable quantity. Which floor is ok on the basis of customer investment and the geographical position of land, ownership of land, cost of land, communication of builders, etc. To buy a flat, customers have to concentrate in some criteria and to decide the priority on the criteria. After the initial screening, customers select four possible alternatives / Flats namely W_1, W_2, W_3, W_4 for further evaluation. A decision maker selects seven attributes namely Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7 that help the customer to select the best one.

- **Fire safety (Q_1):**

When clients purchase an apartment on a higher floor, fire safety is the most critical consideration. To do so, the consumer must be aware that the fitness for occupancy of any apartment can be determined by whether it has received an Occupancy Certificate (OC) from the local authorities. Customers can use OC to determine whether or not a structure was built in accordance with the permitted designs. When purchasing an apartment, buyers should seek the copy of the OC. When the fire department issues clearances, the builder can seek the occupancy certificate. As a result, when clients buy a flat with OC, they know it passes the fire department's safety requirements.

- **Floor deviations (Q_2):**

When a customer is looking at buying a flat, floor deviation is a vital factor to consider. On occasion, unauthorized deviations from construction plans occur on the building's top floor. If clients are purchasing a flat on the top level, make sure there are no deviations from the norm. It is a good idea to inspect the floor and make sure that the property has all of the essential approvals. Another thing to keep in mind is that the lowest floors are the most pest-prone, with rats, snakes, and other animals freely entering the lower units. Higher severe road noise can sometimes be heard from all sides and only subsides beyond 12/13-th floor. So, based on the floor deviations, the customer must select which one is the best for him.

- **Vantage point (Q_3):**

Consider a higher floor if the view from your clients' apartment is vital to you, as they often provide the best available vantage points. The view is a major consideration for apartments nearby sea or in a scenic area. Floor rise charges will apply in an under-construction flat, making living on upper floors slightly more expensive. The benefits of living on a higher floor are numerous. When compared to those on the ground and lower floors, you receive better views of your neighbourhood, better light and ventilation, and are less affected by street-level noises. Mosquitoes and rodents are usually not a problem on higher floors (mainly rats).

- **Mobile network and power consumption (Q_4):**

Whole world is going to be digitalized, so that online communication is going to very first. In numerous metro towns, the construction of high-rise apartments with as much as 40 floors has become commonplace. In Mumbai, for example, high-rise buildings can reach 40 floors, while skyscrapers in Delhi-NCR average 25 floors. If you choose a higher floor, ensure sure the flat has appropriate network coverage. Lower floors are often cooler and use less energy than higher floors. This is a significant consideration in cities with long, hot summers.

- **Connection, service-related factors (Q_5):**

This is yet another significant factor for clients to consider. Before purchasing a property, be certain that the floor is equipped with CCTV Camera. Also, when you buy an apartment on any floor, verify the corridor area, which is the sole open place outside your flat. As a direct consequence, you should double-check that you have adequate space outside of your flat, as corridor sizes differ between apartment complexes. Aside from that, keep in mind that several service providers do not even offer on upper floors, for example, broadband.

- **Choose the right builder (Q_6):**

Before buying, choosing the right builder is very important because in some cases builder is unable to provide the customer satisfaction. They create many problems and making many false statements. So, the feedback and certificate of the builder is too important when it comes to deciding on the right project and floor to buy a flat on, make sure you to choose trusted builder with a solid track record. It is your right and responsibility as a house buyer to verify with the Real Estate Regulatory Authority to see if the builder has registered the project (RERA).

- **Local infrastructure around the society and well connectivity (Q_7):**

In determining a domestic property's current and future worth, the infrastructure in and around it is critical. Roads linking to the community and in-roads within the population, for example, should be well-built and preserved. Ascertain that the project is convenient from significant areas of the city and that governmental and non - governmental transit are well connected. Calculate routes from the city's prominent landmarks. You can do some investigation on the area and see what public transportation choices are available, such as rail, buses, and cabs. Also keep an eye out for future infrastructure plans in the area, such as a projected metro line or freeway, as well as adjacent entertainment alternatives.

The comparison of criteria by the rating from 1 to 9, are given in the following table.

Table-1: (Comparison of Criteria)

Criteria	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	
	7	9	4	3	6	2	1	Best Criteria: Q_7
Q_1								2
Q_2								1
Q_3								5
Q_4								6
Q_5								4
Q_6								8
Q_7								9
Worst Criteria: Q_2								

By using eq. (1) and eq. (2), we obtain the weights of the attributes. The weights are given in the following table.

Table-2: (Calculation of weights using BWM)

Criteria	**Weights** ($=w_i$)
Fire safety (Q_1)	0.05284016

Floor deviations (Q_2)	0.04109790
Vantage point (Q_3)	0.09247028
Mobile network and power consumption (Q_4)	0.1232937
Connection, service-related factors (Q_5)	0.06164685
Choose the right builder (Q_6)	0.2587700
Local infrastructure around the society and well connectivity (Q_7)	0.3698811
Consistency Rate (C_R)	0.6301189

Suppose the decision maker provides his/her evaluation information for the alternatives with respect to the attributes by using SVNNs, then the decision matrix is constructed.

Decision Matrix (D):

D	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
W_1	(0.7,0.3,0.2)	(0.7,0.1,0.2)	(0.9,0.3,0.1)	(0.8,0.1,0.3)	(0.8,0.2,0.1)	(0.9,0.2,0.2)	(0.7,0.2,0.2)
W_2	(0.8,0.2,0.4)	(0.6,0.0,0.2)	(0.8,0.1,0.1)	(0.9,0.2,0.2)	(0.9,0.1,0.2)	(0.8,0.2,0.1)	(0.8,0.1,0.2)
W_3	(0.8,0.3,0.1)	(0.8,0.2,0.2)	(1.0,0.2,0.1)	(0.7,0.2,0.1)	(0.8,0.3,0.2)	(0.7,0.2,0.1)	(1.0,0.3,0.2)
W_4	(0.6,0.2,0.1)	(0.9,0.2,0.3)	(0.8,0.1,0.2)	(0.9,0.4,0.2)	(0.7,0.2,0.2)	(0.7,0.1,0.2)	(0.8,0.1,0.3)

Score Matrix (D^*):

D^*	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
W_1	0.564799	0.799393	0.768877	0.716865	0.842201	0.807487	0.702178
W_2	0.511229	0.787653	0.928855	0.807487	0.872894	0.842201	0.842201
W_3	0.716865	0.762999	0.895568	0.799393	0.647871	0.799393	0.758338
W_4	0.737567	0.710420	0.842201	0.592041	0.702178	0.799393	0.716865

[In the above table, we find all the score values by taking r= 0.01]

Normalized Decision Matrix (N):

N	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
W_1	0.441269	0.361863	0.446502	0.488277	0.545455	0.497031	0.463878
W_2	0.399416	0.356548	0.539404	0.550002	0.565334	0.518398	0.556381
W_3	0.560075	0.345388	0.520074	0.544489	0.419597	0.492049	0.500978
W_4	0.576250	0.321587	0.489083	0.403256	0.454769	0.492049	0.473580

Weighted Normalized Decision Matrix (V):

V	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
W_1	0.023317	0.014872	0.041288	0.060201	0.033626	0.183842	0.171580
W_2	0.021105	0.014653	0.049879	0.067812	0.034851	0.191746	0.205795
W_3	0.029594	0.014195	0.048091	0.067132	0.025867	0.182000	0.185302
W_4	0.030449	0.013216	0.045226	0.049719	0.028035	0.182000	0.175168

Neutrosophic Positive Ideal Solution (I^+) and Neutrosophic Negative Ideal Solution (I^-):

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7
W_1	0.023317	0.014872	0.041288	0.060201	0.033626	0.183842	0.171580
W_2	0.021105	0.014653	0.049879	0.067812	0.034851	0.191746	0.205795
W_3	0.029594	0.014195	0.048091	0.067132	0.025867	0.182000	0.185302
W_4	0.030449	0.013216	0.045226	0.049719	0.028035	0.182000	0.175168
I^+	0.030449	0.014872	0.049879	0.067812	0.034851	0.191746	0.205795
I^-	0.021105	0.013216	0.041288	0.049719	0.025867	0.182000	0.171580

Distance of Each Alternative from NPIS and NNIS:

	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	S_j^+	S_j^-
W_1	0.023317	0.014872	0.041288	0.060201	0.033626	0.183842	0.171580	0.037646223	0.013457438
W_2	0.021105	0.014653	0.049879	0.067812	0.034851	0.191746	0.205795	0.041828099	0.296781428
W_3	0.029594	0.014195	0.048091	0.067132	0.025867	0.182000	0.185302	0.27572937	0.27572937
W_4	0.030449	0.013216	0.045226	0.049719	0.028035	0.182000	0.175168	0.264977289	0.264977289

Performance Score:

	S_j^+	S_j^-	$P_j = \frac{S_j^-}{S_j^- + S_j^+}$
W_1	0.037646223	0.013457438	0.263336092
W_2	0.041828099	0.296781428	0.876470991
W_3	0.27572937	0.27572937	0.5
W_4	0.264977289	0.264977289	0.5

The ascending order of performance score associated with each alternative is $P_1 < P_4 = P_3 < P_2$. Hence, W_2 is the most suitable flat for the customer.

5. Conclusion

In this paper, we used some suitable attributes for decision making to a better choice of a flat among the available flats. Also, we used two important methods BWM and TOPSIS to select the appropriate flat among the available flats under the SVNS environment, where the BWM is mainly used for determining the weights of the attributes, and TOPSIS is used for ranking the possible alternatives/flats.

The data used in this paper has not taken from any source. We have just considered these numbers for the verification of our algorithm. However, this algorithm can apply for any real source data.

The developed BWM-TOPSIS can be utilized in different neutrosophic environments such as refined neutrosophic set [27], rough neutrosophic set [28], interval neutrosophic set [29], neutrosophic soft set [30], neutrosophic soft expert set [31], bipolar neutrosophic set [32], pentapartitioned neutrosophic set [33, 34], etc.

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