Neutrosophic TOPSIS Method with a New Aggregation Operator for Solving MADM Problems

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Abstract

In recent years, neutrosophic sets has become a subject of great interest for many researchers and has been widely applied to multi attribute decision making (MADM) problems and the single valued trapezoidal neutrosophic number (SVTN) is used to deal with uncertain information. In this paper, a new aggregation operator namely single valued trapezoidal neutrosophic ordered weighted harmonic averaging (SVTNOWHA) operator is proposed for solving MADM problems. The combining ideas of the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) and SVTNOWHA operator, which can be prove the accuracy of decision maker. A SVTNOWHA – TOPSIS approach for MADM problems with SVTN information is proposed. Finally, an example is provided to elaborate the proposed method. In the proposed SVTNOWHA - TOPSIS approach, the ratings of alternatives and attributes for illustrative problem are represented by the SVTN numbers. This study has developed the SVTNOWHA - TOPSIS method using the neutrosophic information in order to solve the investment company problem. In future, the proposed method may also be applied to solve other MADM problems such as enterprise selection, supplier selection, low carbon logistics service provider selection and investor selection.

Keywords
Neutrosophic Set, Single Valued Trapezoidal Neutrosophic Number, Multi attribute decision making, Aggregation Operator, TOPSIS.

1. Introduction
Multi attribute decision making (MADM) is an important part of decision process. In 1981, Hwang and Yoon developed the Technique for Order Preference by Similarity to Ideal Situation (TOPSIS) for solving multi criteria decision making (MCDM) problems. In 1965, Zadeh developed the theory of fuzzy sets and fuzzy logic when applied to a various type of MCDM problems. Moataz and Aminah (2016) presented TOPSIS method based on prioritized aggregation operators to solve MCDM problems. Muhammad and Fazal (2017) proposed fuzzy TOPSIS method for solving MCDM problems. Jibin et al. (2018) presented TOPSIS and fuzzy preference relations based on hesitant fuzzy set for solving MADM problems. S. Zeng and Y. Xiao (2018) presented hesitant fuzzy MADM using TOPSIS and distance measures. Gia Sirbiladze et al. (2019) developed hesitant Fuzzy TOPSIS method for solving Facility Location Selection Problem. Desyta and Suharyanto (2019) presented Fuzzy TOPSIS method for determining priority of small dams construction. Dhiraj Kumar and Sharifuddin Mondal (2019) presented fuzzy TOPSIS method for optimizing of forging problems. Sindhu et al. (2019) developed TOPSIS method for solving decision making problems under picture fuzzy sets. Aydemir and Gunduz (2020) presented fermatean fuzzy TOPSIS method with dombi aggregation operators for solving MCDM problems. A. Fahmi et al. (2020) presented trapezoidal linguistic cubic fuzzy TOPSIS method and applied group decision making problems. Rana Muhammad Zulqarnain et al. (2020) established generalization of fuzzy TOPSIS to solve MCDM problems. Zhong and Deng (2020) proposed audit risk evaluation methods based on TOPSIS and choquet fuzzy integral. K. H. G. Bae et al. (2021) presented a fuzzy Analytic Hierarchy Process (AHP) and TOPSIS integrated approach for analysis an airline

financial and operational performances. Omar et al. (2021) established hierarchical fuzzy TOPSIS method for solving decision making problems. Baharin et al. (2021) presented fuzzy TOPSIS method for manager selection problems.

By considering the non-membership degree to the concept of fuzzy set, Atanassov (1965) proposed the concept of an intuitionistic fuzzy set which is characterized by membership degree and non-membership degree. Joshi and Kumar (2014) proposed a method based on distance measure and intuitionistic fuzzy entropy based on TOPSIS methods for solving decision making problems. Wang and Li (2015) established intuitionistic fuzzy set TOPSIS method and applied an application of Employee Performance Appraisal. Ummusalma and Selvakumari (2017) presented TOPSIS method for decision making problems under triangular intuitionistic fuzzy numbers. Thiagarasu and Dharmarajan (2017) proposed intuitionistic fuzzy TOPSIS and entropy weight information methods for solving MCDM problems. Raj Mishra et al. (2017) introduced intuitionistic fuzzy weighted measures (IFWM) with TOPSIS method MCDM. Harish Garg and Kamal Kumar (2018) presented an extended TOPSIS method under the linguistic interval-valued intuitionistic fuzzy information environment. Zheng et al. (2020) presented TOPSIS method based on entropy measure for intuitionistic trapezoidal fuzzy sets and applied MADM problems. Naziya and prakash (2021) presented extension TOPSIS method to group decision making problems based on intuitionistic fuzzy numbers. Kahraman and Alkan (2021) developed circular intuitionistic fuzzy TOPSIS method for applied supplier selection problems. Fengling Wang (2021) presented Teaching effect evaluation of College English based on TOPSIS method under interval valued intuitionistic fuzzy information.

In 1995, Smarandache initially proposed the concept neutrosophic sets. Pramanik et al. (2015) proposed TOPSIS method for solving single valued neutrosophic soft set based MADM problems. Pranab et al. (2015) proposed TOPSIS method for MADM problems under single-valued neutrosophic environment. Elhassouny and Smarandache (2016) proposed Neutrosophic-simplified-TOPSIS method applied for MCDM problems. Pranab et al. (2018) developed TOPSIS method for solving MADM problems under trapezoidal neutrosophic environment. Ji Chen et al. (2018) presented a technique based on single-valued neutrosophic linguistic ordered weighted averaging distance (SVNLOWAD) based on TOPSIS method for solving green supplier selection in low-carbon supply chains. B. C. Giri et al. (2018) developed TOPSIS method for MADM problems under interval trapezoidal neutrosophic numbers. Nancy and Harish (2019) developed a novel TOPSIS method for solving single-valued neutrosophic MCDM. Shouzhen Zeng et al. (2019) established correlation based TOPSIS method for MADM problems with single-valued neutrosophic information. N. A. Nabeeh et al. (2020) proposed integrated neutrosophic TOPSIS method for solving personnel selection problems. Faruk and Fatih (2020) developed MCDM problems based on TOPSIS approach under type 2 single valued neutrosophic environment. Saqlain et al. (2020) proposed a new approach of neutrosophic soft set with generalized fuzzy TOPSIS for solving MCDM problem. Rana Muhammad Zulqarnain et al. (2020) developed integrated model for solve neutrosophic TOPSIS method and applied MCDM problems. B. C. Giri et al. (2020) extended TOPSIS method for MADM problems based on single valued neutrosophic hesitant fuzzy set and interval neutrosophic hesitant fuzzy set. J. Wu et al. (2021) extended multi person TOPSIS method for m-polar single-valued neutrosophic sets (m-PSVNSs). Xu and Peng (2021) proposed TOPSIS and TODIM (an acronym in Portuguese of interactive and multiple attribute decision making) methods for solving MADM problems under multi valued neutrosophic sets. Ridvan et al. (2021) developed divergence (distance), projection (similarity), and likelihood (magnitude) –TOPSIS (DPL – TOPSIS) method for solving MCDM problems. Geng et al. (2021) established the single-valued neutrosophic linguistic combined and weighted distance measure (SVNLCWD)-TOPSIS method for solving a low carbon logistics service provider selection problem.

Based on literature review that reflects no research has been carried out on SVTNOWHA – TOPSIS approach for solving MADM problems and to merge this gap, we established SVTNOWHA – TOPSIS approach in neutrosophic information. In order to further study of proposed approach of SVTN numbers, simplify its comparison and application in MADM problems and the paper attempts do to the following results:

1. To present the single valued trapezoidal neutrosophic ordered weighted harmonic averaging (SVTNOWHA) operator.
2. By compared with SVTNOWHA – TOPSIS approach has including some advantages.
3. To propose a simple approach for solving MADM problems when the performance ratings are expressed in SVTN numbers.

4. TOPSIS method both consider as positive and negative ideal solutions in SVTN numbers and the distance measures between the alternatives and ideal solutions of the pairwise comparison between alternatives, it make a simple calculation.
5. The main aim of this proposed method is to choose the best opinion of the alternative of the decision making.

The aim of this paper is to develop a new method which combines SVTNOWHA - TOPSIS method and examines its application based on SVTN numbers. This paper is organized as follows. Section 2 depicts some review of basic concepts. Section 3 reviews single valued trapezoidal neutrosophic ordered weighted harmonic operator. Section 4 discusses method for MADM problem. Section 5 is the conclusion of the paper.

2. Preliminaries

In this section, we review some basic concepts about the single valued trapezoidal neutrosophic number.

Definition 2.1 (Smarandache 1998) Let X be a non-empty set. Then a neutrosophic set A of X is defined as $A = \{< x, (T_A(x), I_A(x), F_A(x)) > | x \in X\}, T_A: A \to [0,1], I_A: A \to [0,1], F_A: A \to [0,1]$ to satisfy the condition $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$ for every $x \in A$.The function T_A, I_A and F_A are said to be the degree of truth membership function $T_A(x)$, indeterminacy membership function $I_A(x)$and falsity membership function $F_A(x)$of A, respectively.

Definition 2.2 (Pranab et al. 2018) Let $a_l, a_{m1}, a_{m2}, a_u \in R$ such that $a_l \leq a_{m1} \leq a_{m2} \leq a_u$. A single valued trapezoidal neutrosophic number $\tilde{a} =< (a_l, a_{m1}, a_{m2}, a_u); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >$ is a special set on the real number set R, whose truth membership, indeterminacy membership and falsity membership functions are given as follows.

$$T_{\tilde{a}}(x) = \begin{cases} \left(\frac{x-a_l}{a_{m1}-a_l}\right) T_{\tilde{a}}, & a_l \leq x \leq a_{m1} \\ T_{\tilde{a}}, & a_{m1} \leq x \leq a_{m2} \\ \left(\frac{a_u-x}{a_u-a_{m2}}\right) T_{\tilde{a}}, & a_{m2} \leq x \leq a_u \\ 0, & otherwise \end{cases} \quad I_{\tilde{a}}(x) = \begin{cases} \left(\frac{(a_{m1} - x + (x-a_l) I_{\tilde{a}})}{a_{m1}-a_l}\right), & a_l \leq x \leq a_{m1} \\ I_{\tilde{a}}, & a_{m1} \leq x \leq a_{m2} \\ \left(\frac{(x-a_{m2}+(a_u-x) I_{\tilde{a}})}{a_u-a_{m2}}\right), & a_{m2} \leq x \leq a_u \\ 0, & otherwise \end{cases}$$

$$F_{\tilde{a}}(x) = \begin{cases} \left(\frac{(a_{m1} - x + (x-a_l) F_{\tilde{a}})}{a_{m1}-a_l}\right), & a_l \leq x \leq a_{m1} \\ F_{\tilde{a}}, & a_{m1} \leq x \leq a_{m2} \\ \left(\frac{(x-a_{m2}+(a_u-x) F_{\tilde{a}})}{a_u-a_{m2}}\right), & a_{m2} \leq x \leq a_u \\ 0, & otherwise \end{cases}$$

Definition 2.3 (Pranab et al. 2018) Let $\tilde{a} =< (a_l, a_{m1}, a_{m2}, a_u); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >$ and $\tilde{b} =< (b_l, b_{m1}, b_{m2}, b_u); T_{\tilde{b}}, I_{\tilde{b}}, F_{\tilde{b}} >$ be two single valued trapezoidal neutrosophic numbers and $\lambda \neq 0$, then

i) $\tilde{a} + \tilde{b} =< (a_l + b_l, a_{m1} + b_{m1}, a_{m2} + b_{m2}, a_u + b_u); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >$

ii) $\tilde{a} - \tilde{b} =< a_l - b_u, a_{m1} - b_{m2}, a_{m2} - b_{m1}, a_u - b_l); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >$

iii) $$\tilde{a}\tilde{b} = \begin{cases} < (a_l b_l, a_{m1} b_{m1}, a_{m2} b_{m2}, a_u b_u); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u > 0, b_u > 0) \\ < (a_l b_u, a_{m1} b_{m2}, a_{m2} b_{m1}, a_u b_l); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u < 0, b_u > 0) \\ < (a_u b_u, a_{m2} b_{m2}, a_{m1} b_{m1}, a_l b_l); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u < 0, b_u < 0) \end{cases}$$

iv) $$\frac{\tilde{a}}{\tilde{b}} = \begin{cases} < \left(\frac{a_l}{b_u}, \frac{a_{m1}}{b_{m2}}, \frac{a_{m2}}{b_{m1}}, \frac{a_u}{b_l}\right); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u > 0, b_u > 0) \\ < \left(\frac{a_u}{b_u}, \frac{a_{m2}}{b_{m2}}, \frac{a_{m1}}{b_{m1}}, \frac{a_l}{b_l}\right); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u < 0, b_u > 0) \\ < \left(\frac{a_u}{b_l}, \frac{a_{m2}}{b_{m1}}, \frac{a_{m1}}{b_{m2}}, \frac{a_l}{b_u}\right); \min(T_{\tilde{a}}, T_{\tilde{b}}), \max(I_{\tilde{a}}, I_{\tilde{b}}), \max(F_{\tilde{a}}, F_{\tilde{b}}) >, (a_u < 0, b_u < 0) \end{cases}$$

v) $$\lambda\tilde{a} = \begin{cases} < (\lambda a_l, \lambda a_{m1}, \lambda a_{m2}, \lambda a_u); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >, (\lambda > 0) \\ < (\lambda a_u, \lambda a_{m2}, \lambda a_{m1}, \lambda a_l); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >, (\lambda < 0) \end{cases}$$

vi) $\tilde{a}^{-1} =< \left(\frac{1}{a_u}, \frac{1}{a_{m2}}, \frac{1}{a_{m1}}, \frac{1}{a_l}\right); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >, (\tilde{a} \neq \tilde{0})$

Definition 2.4 (Pranab et al. 2018) Let $\tilde{a} =< (a_l, a_{m1}, a_{m2}, a_u); T_{\tilde{a}}, I_{\tilde{a}}, F_{\tilde{a}} >$ and

$\tilde{b} =< (b_l, b_{m1}, b_{m2}, b_u); T_{\tilde{b}}, I_{\tilde{b}}, F_{\tilde{b}} >$ be two single valued trapezoidal neutrosophic numbers, then the normalized hamming distance between $\tilde{a}$ and $\tilde{b}$ is defined as follows:

$$\boldsymbol{d}(\tilde{a}, \tilde{b}) = \frac{1}{12}\big(|a_l(2 + T_{\tilde{a}} - I_{\tilde{a}} - F_{\tilde{a}}) - b_l(2 + T_{\tilde{b}} - I_{\tilde{b}} - F_{\tilde{b}})| + |a_{m1}(2 + T_{\tilde{a}} - I_{\tilde{a}} - F_{\tilde{a}}) - b_{m1}(2 + T_{\tilde{b}} - I_{\tilde{b}} - F_{\tilde{b}})| + |a_{m2}(2 + T_{\tilde{a}} - I_{\tilde{a}} - F_{\tilde{a}}) - b_{m2}(2 + T_{\tilde{b}} - I_{\tilde{b}} - F_{\tilde{b}})| + |a_u(2 + T_{\tilde{a}} - I_{\tilde{a}} - F_{\tilde{a}}) - b_u(2 + T_{\tilde{b}} - I_{\tilde{b}} - F_{\tilde{b}})|\big)$$

3. Single valued trapezoidal neutrosophic ordered weighted harmonic averaging operator

This section, reviews an aggregation operator namely, single valued trapezoidal neutrosophic ordered weighted harmonic averaging operator on the single valued trapezoidal neutrosophic numbers.

Definition 3.1 (Paulraj and Tamilarasi 2022) Let $\tilde{a}_j =< (a_{jl}, a_{jm1}, a_{jm2}, a_{ju}); T_{\tilde{a}j}, I_{\tilde{a}j}, F_{\tilde{a}j} >$ be a collection of single valued trapezoidal neutrosophic numbers and $w = (w_1, w_2, \dots, w_n)^T$ be the associated weighted vector. Then the Single Valued Trapezoidal Neutrosophic Ordered Weighted Harmonic Averaging (SVTNOWHA) Operator is defined by

$$SVTNOWHA(\tilde{a}_1, \tilde{a}_2, \dots, \tilde{a}_n) = \frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{\tilde{b}_j}\right)}$$

Where $\tilde{b}_j$ is the largest j^{th} element in the collection of $\tilde{a}_j$ and $\tilde{b}_j =< (b_{jl}, b_{jm1}, b_{jm2}, b_{ju}); T_{\tilde{b}j}, I_{\tilde{b}j}, F_{\tilde{b}j} >$.
Here $w_j \in [0,1], \sum_{j=1}^{n} w_j = 1$.

Theorem 3.2 Let $\tilde{a}_j =< (a_{jl}, a_{jm1}, a_{jm2}, a_{ju}); T_{\tilde{a}j}, I_{\tilde{a}j}, F_{\tilde{a}j} >, (j = 1,2, \dots, n)$ be a collection of single valued trapezoidal Neutrosophic number and $w = (w_1, w_2, \dots, w_n)^T$ be a weighted vector of $\tilde{a}_j$, where $w_j \in [0,1], \sum_{j=1}^{n} w_j = 1$, then the result of aggregation operator

$$\text{SVTNOWHA}(\tilde{a}_1, \tilde{a}_2, \dots, \tilde{a}_n) = \frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{\tilde{b}_j}\right)}$$

$$=< \left(\frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{b_{jl}}\right)}, \frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{b_{jm1}}\right)}, \frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{b_{jm2}}\right)}, \frac{1}{\left(\sum_{j=1}^{n} \frac{w_j}{b_{ju}}\right)} \right); \min_j\{T_{\tilde{b}j}\}, \max_j\{I_{\tilde{b}j}\}, \max_j\{F_{\tilde{b}j}\} >$$

Proof: This theorem can be proved by mathematical induction.
When n=2, then SVTNOWHA $(\tilde{a}_1, \tilde{a}_2)$ is calculated as follows:

$$\frac{1}{\frac{w_1}{\tilde{b}_1} + \frac{w_2}{\tilde{b}_2}} = \frac{1}{\frac{w_1}{<(b_{1l}, b_{1m1}, b_{1m2}, b_{1u}); T_{\tilde{b}1}, I_{\tilde{b}1}, F_{\tilde{b}1}>} + \frac{w_2}{<(b_{2l}, b_{2m1}, b_{2m2}, b_{2u}); T_{\tilde{b}2}, I_{\tilde{b}2}, F_{\tilde{b}2}>}}$$

$$= \frac{1}{w_1 < \left(\frac{1}{b_{1u}}, \frac{1}{b_{1m2}}, \frac{1}{b_{1m1}}, \frac{1}{b_{1l}}\right); T_{\tilde{b}1}, I_{\tilde{b}1}, F_{\tilde{b}1} > + w_2 < \left(\frac{1}{b_{2u}}, \frac{1}{b_{2m2}}, \frac{1}{b_{2m1}}, \frac{1}{b_{2l}}\right); T_{\tilde{b}2}, I_{\tilde{b}2}, F_{\tilde{b}2} >}$$

$$= \frac{1}{< \left(\left(\frac{w_1}{b_{1u}} + \frac{w_2}{b_{2u}}\right), \left(\frac{w_1}{b_{1m2}} + \frac{w_2}{b_{2m2}}\right), \left(\frac{w_1}{b_{1m1}} + \frac{w_2}{b_{2m1}}\right), \left(\frac{w_1}{b_{1l}} + \frac{w_2}{b_{2l}}\right) \right); \min(T_{\tilde{b}1}, T_{\tilde{b}2}), \max(I_{\tilde{b}1}, I_{\tilde{b}2}), \max(F_{\tilde{b}1}, F_{\tilde{b}2}) >}$$

$$=< \left(\frac{1}{\left(\frac{w_1}{b_{1l}} + \frac{w_2}{b_{2l}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1m1}} + \frac{w_2}{b_{2m1}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1m2}} + \frac{w_2}{b_{2m2}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1u}} + \frac{w_2}{b_{2u}}\right)} \right); \min\ (T_{\tilde{b}1}, T_{\tilde{b}2}), \max\ (I_{\tilde{b}1}, I_{\tilde{b}2}), \max\ (F_{\tilde{b}1}, F_{\tilde{b}2}) >$$

Therefore, $SVTNOWHA(\tilde{a}_1, \tilde{a}_2) = \frac{1}{\frac{w_1}{\tilde{b}_1} + \frac{w_2}{\tilde{b}_2}}$

$$=< \left(\frac{1}{\left(\frac{w_1}{b_{1l}}+\frac{w_2}{b_{2l}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1m1}}+\frac{w_2}{b_{2m1}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1m2}}+\frac{w_2}{b_{2m2}}\right)}, \frac{1}{\left(\frac{w_1}{b_{1u}}+\frac{w_2}{b_{2u}}\right)} \right); \min(T_{\tilde{b}1}, T_{\tilde{b}2}), \max(I_{\tilde{b}1}, I_{\tilde{b}2}), \max(F_{\tilde{b}1}, F_{\tilde{b}2}) >$$

Then the result true for n =2 and assume that the result holds for n=k.

$$\text{SVTNOWHA } (\tilde{a}_1, \tilde{a}_2, \dots, \tilde{a}_k) =< \left(\frac{1}{\left(\sum_{j=1}^{k} \frac{w_j}{b_{jl}}\right)}, \frac{1}{\left(\sum_{j=1}^{k} \frac{w_j}{b_{jm1}}\right)}, \frac{1}{\left(\sum_{j=1}^{k} \frac{w_j}{b_{jm2}}\right)}, \frac{1}{\left(\sum_{j=1}^{k} \frac{w_j}{b_{ju}}\right)} \right); \min_j\{T_{\tilde{b}j}\}, \max_j\{I_{\tilde{b}j}\}, \max_j\{F_{\tilde{b}j}\} >$$

For n =k+1, using the above result and arithmetic operations laws, we have

$$\text{SVTNOWHA } (\tilde{a}_1, \tilde{a}_2, \dots, \tilde{a}_k, \tilde{a}_{k+1}) = \frac{1}{\left(\sum_{j=1}^{k} \frac{w_j}{\tilde{b}_j} + \frac{w_{k+1}}{\tilde{b}_{k+1}}\right)}$$

$$= \frac{1}{< \left(\left(\sum_{j=1}^{k} \frac{w_j}{\tilde{b}_{ju}} + \frac{w_{k+1}}{\tilde{b}_{(k+1)u}} \right), \left(\sum_{j=1}^{k} \frac{w_j}{\tilde{b}_{jm2}} + \frac{w_{k+1}}{\tilde{b}_{(k+1)m2}} \right), \left(\sum_{j=1}^{k} \frac{w_j}{\tilde{b}_{jm1}} + \frac{w_{k+1}}{\tilde{b}_{(k+1)m1}} \right), \left(\sum_{j=1}^{k} \frac{w_j}{\tilde{b}_{jl}} + \frac{w_{k+1}}{\tilde{b}_{(k+1)l}} \right) \right); \alpha, \beta, \gamma >}$$

Where $\alpha = \min\{T_{\tilde{b}j}, T_{\tilde{b}(k+1)}\}, \beta = \max\{I_{\tilde{b}j}, I_{\tilde{b}(k+1)}\}$ and $\gamma = \max\{F_{\tilde{b}j}, F_{\tilde{b}(k+1)}\}$.

$$=< \left(\frac{1}{\left(\sum_{j=1}^{k+1} \frac{w_j}{b_{jl}}\right)}, \frac{1}{\left(\sum_{j=1}^{k+1} \frac{w_j}{b_{jm1}}\right)}, \frac{1}{\left(\sum_{j=1}^{k+1} \frac{w_j}{b_{jm2}}\right)}, \frac{1}{\left(\sum_{j=1}^{k+1} \frac{w_j}{b_{ju}}\right)} \right); \min_j\{T_{\tilde{b}j}\}, \max_j\{I_{\tilde{b}j}\}, \max_j\{F_{\tilde{b}j}\} >$$

Then the result is true for all n.

4. SVTNOWHA – TOPSIS approach for solving MADM problems

Consider the multi attribute decision making problem with m alternatives and n attributes.
Let $A = (A_1, A_2, \dots, A_m)$ be a set of m alternatives. Let $C = (C_1, C_2, \dots, C_n)$ be the set of n attributes.
Let $D^p = (\tilde{a}_{ij}^p)_{m \times n}$ be the decision matrix of the decision maker p. Where $\tilde{a}_{ij}^p$ is the rating of decision maker p of an alternative A_i with an attribute C_j ($i = 1, 2, \dots, m, j = 1, 2, \dots, n, p = 1,2, \dots, t$). Let $\omega = (\omega_1 \omega_2, \dots, \omega_n)^T$ be the attribute weighted vector satisfying $0 \le \omega_j \le 1, (j = 1, 2, \dots, n)$ and $\sum_{j=1}^{n} \omega_j = 1$.

The following algorithm is proposed to obtain the solution of MADM problem with the SVTN numbers information by using SVTNOWHA -TOPSIS method.

Assume that the decision matrix of the decision maker p is given as follows:

$$D^p = (\tilde{a}_{ij}^p)_{m \times n} = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} & \begin{pmatrix} \tilde{a}_{11}^p & \tilde{a}_{12}^p & \cdots & \tilde{a}_{1n}^p \\ \tilde{a}_{21}^p & \tilde{a}_{22}^p & \cdots & \tilde{a}_{2n}^p \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{m1}^p & \tilde{a}_{m2}^p & \dots & \tilde{a}_{mn}^p \end{pmatrix} \end{array}$$

Where $\tilde{a}_{ij}^p =< (a_{ijl}^p, a_{ijm1}^p, a_{ijm2}^p, a_{iju}^p); T_{ij}^p, I_{ij}^p, F_{ij}^p >, (i = 1,2, \dots, m, j = 1,2, \dots, n, p = 1,2, \dots, t)$ is in the form of single valued trapezoidal neutrosophic number.

Step 1: Compute the normalized decision matrix.
If all the rating in a decision matrix D^p either profit or cost then there is no need of normalization. Otherwise, construct the normalized decision matrix $N^p = (\tilde{r}_{ij}^p)_{m \times n}$. Where $\tilde{r}_{ij}^p$ is the normalized rating of decision maker p of an alternative A_i with an attribute C_j and its computed as follows.

$$\tilde{r}_{ij}^{p} = \begin{cases} \dfrac{\tilde{a}_{ij}^{p}}{\sum_{j=1}^{n} \tilde{a}_{ij}^{p}}, if\ the\ rating\ \tilde{a}_{ij}^{p}\ is\ profit \\ \dfrac{\left(\frac{1}{\tilde{a}_{ij}^{p}}\right)}{\sum_{j=1}^{n}\left(\frac{1}{\tilde{a}_{ij}^{p}}\right)}, if\ the\ rating\ \tilde{a}_{ij}^{p}\ is\ cost \end{cases}$$

$$\text{i.e., } N^{p} = \left(\tilde{r}_{ij}^{p}\right)_{m\times n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{pmatrix} \tilde{r}_{11}^{p} & \tilde{r}_{12}^{p} & \cdots & \tilde{r}_{1n}^{p} \\ \tilde{r}_{21}^{p} & \tilde{r}_{22}^{p} & \cdots & \tilde{r}_{2n}^{p} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{r}_{m1}^{p} & \tilde{r}_{m2}^{p} & \dots & \tilde{r}_{mn}^{p} \end{pmatrix} \end{array}$$

Where $\tilde{r}_{ij}^{p} =< \left(r_{ijl}^{p}, r_{ijm1}^{p}, r_{ijm2}^{p}, r_{iju}^{p}\right); T_{ij}^{p}, I_{ij}^{p}, F_{ij}^{p} >, i = 1,2, \dots, m, j = 1,2, \dots, n, p = 1,2, \dots, t$ is in the form of single valued trapezoidal neutrosophic number.

Step 2: Compute the aggregated decision matrix
To aggregate all experts' ratings for each alternative with respect to each attribute and the SVTNOWHA operator are used and aggregated matrix can be represented as follows:

$$R = \left(\tilde{R}_{ij}\right)_{m\times n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{pmatrix} \tilde{R}_{11} & \tilde{R}_{12} & \cdots & \tilde{R}_{1n} \\ \tilde{R}_{21} & \tilde{R}_{22} & \cdots & \tilde{R}_{21} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{R}_{m1} & \tilde{R}_{m2} & \dots & \tilde{R}_{mn} \end{pmatrix} \end{array}$$

Where $\tilde{R}_{ij} = SVTNOWHA\left(\tilde{r}_{ij}^{1}, \tilde{r}_{ij}^{2}, \dots, \tilde{r}_{ij}^{t}\right)$ and $\tilde{R}_{ij} =< \left(R_{ijl}, R_{ijm1}, R_{ijm2}, R_{iju}\right); T_{ij}, I_{ij}, F_{ij} >$ $i = 1,2, \dots, m, j = 1,2, \dots, n, p = 1,2, \dots, t$ is in the form of single valued trapezoidal neutrosophic number. Here, w is the associate weight vector which can be obtained by the fuzzy linguistic quantifier is "most" with the pair of $(\alpha, \beta) = (0.3, 0.8)$.

Step 3: Determine the single valued trapezoidal neutrosophic positive and negative ideal solutions.
In the aggregated neutrosophic decision matrix, the single valued trapezoidal neutrosophic positive ideal solution and the single valued trapezoidal neutrosophic negative ideal solution are defined as follows

$$\tilde{r}_{j}^{+} = \left(\tilde{r}_{1}^{+}, \tilde{r}_{2}^{+}, \dots, \tilde{r}_{n}^{+}\right) \text{ and } \tilde{r}_{j}^{-} = \left(\tilde{r}_{1}^{-}, \tilde{r}_{2}^{-}, \dots, \tilde{r}_{n}^{-}\right)$$

Where, $\tilde{r}_{j}^{+} =< \left(r_{jl}^{+}, r_{jm1}^{+}, r_{jm2}^{+}, r_{ju}^{+}\right); T_{j}^{+}, I_{j}^{+}, F_{j}^{+} >, j = 1,2, \dots, n$

$$\tilde{r}_{j}^{+} =< \left(\max_{j}\left(R_{ijl}\right), \max_{j}\left(R_{ijm1}\right), \max_{j}\left(R_{ijm2}\right), \max_{j}\left(R_{iju}\right)\right);\ \max_{j}\left(T_{ij}\right), \min_{j}\left(I_{ij}\right), \min_{j}\left(F_{ij}\right) >, i = 1,2, \dots, m$$

$$\tilde{r}_{j}^{-} =< \left(r_{jl}^{-}, r_{jm1}^{-}, r_{jm2}^{-}, r_{ju}^{-}\right); T_{j}^{-}, I_{j}^{-}, F_{j}^{-} >, j = 1,2, \dots, n$$

$$\tilde{r}_{j}^{-} =< \left(\min_{j}\left(R_{ijl}\right), \min_{j}\left(R_{ijm1}\right), \min_{j}\left(R_{ijm2}\right), \min_{j}\left(R_{iju}\right)\right);\ \min_{j}\left(T_{ij}\right), \max_{j}\left(I_{ij}\right), \max_{j}\left(F_{ij}\right), >, i = 1,2, \dots, m$$

Step 4: Compute the distance separation measures.
For the separation measures d_i^{+} and d_i^{-} of each alternative from the ideal solutions can be determined by
$d_i^{+} = \sum_{j=1}^{n} \omega_j d\left(\tilde{R}_{ij}, \tilde{r}_{j}^{+}\right)$ and $d_i^{-} = \sum_{j=1}^{n} \omega_j d\left(\tilde{R}_{ij}, \tilde{r}_{j}^{-}\right), i = 1,2, \dots, m$

Step 5: Calculate the relative closeness coefficient (RCC).
The RCC of an alternative A_i w. r. to the single valued trapezoidal neutrosophic positive and negative ideal solutions is computed as

$$R_i = \frac{d_i^-}{(d_i^+ + d_i^-)}, i = 1,2,\dots,m, 0 \le R_i \le 1$$

Step 6: Select the best alternative.
After computation of RCC ranking all the alternatives A_i $(i = 1,2,\dots,m)$ according to the closeness coefficient R_i, the greater the value R_i is the better the alternative A_i.

4.1 An Illustrative Example

In this section, we are going to develop MADM problem in order to illustrate the new approach. The following problem is adapted from Pramanik and Mallick (2019) and applied with SVTNOWHA – TOPSIS method.
Suppose that an investment company intends to invest a sum of money in the best option. The company constitutes a board of decision makers with three members. The decision makers determine the alternatives to invest money. The alternatives are Computer company (A_1), Arms company (A_2), Car company (A_3) and Food company(A_4). The decision makers take the decision based on the following three attributes are Risk factor (C_1), Growth factor (C_2) and Environment impact (C_3). Assume that the weight of attributes for the decision makers is $\omega = (0.3,0.5,0.2)^T$. The ratings of the all alternatives $A_i, (i = 1,2,3,4)$with respect to attributes $C_j, (j = 1,2,3)$ according to the SVTN numbers are given in Table 1, 2 and 3.

Table 1. Decision matrix provided by an expert D^1

Alternatives	C_1	C_2	C_3
A_1	$<(0.4,0.5,0.5,0.6); 0.3,0.1,0.2>$	$<(0.3,0.4,0.5,0.5); 0.4,0.2,0.3>$	$<(0.2,0.3,0.4,0.5); 0.3,0.3,0.2>$
A_2	$<(0.3,0.3,0.4,0.4); 0.5,0.3,0.4>$	$<(0.2,0.3,0.3,0.3); 0.5,0.2,0.5>$	$<(0.4,0.5,0.6,0.6); 0.4,0.2,0.3>$
A_3	$<(0.4,0.4,0.5,0.6); 0.4,0.3,0.3>$	$<(0.3,0.4,0.5,0.6); 0.3,0.4,0.2>$	$<(0.1,0.2,0.2,0.3); 0.3,0.2,0.1>$
A_4	$<(0.3,0.4,0.5,0.5); 0.2,0.3,0.1>$	$<(0.2,0.3,0.3,0.6); 0.5,0.2,0.2>$	$<(0.3,0.4,0.7,0.7); 0.5,0.4,0.3>$

Table 2. Decision matrix provided by an expert D^2

Alternatives	C_1	C_2	C_3
A_1	$<(0.6,0.7,0.7,0.8); 0.3,0.4,0.1>$	$<(0.5,0.6,0.6,0.7); 0.5,0.4,0.3>$	$<(0.3,0.5,0.6,0.7); 0.5,0.4,0.2>$
A_2	$<(0.5,0.6,0.7,0.7); 0.5,0.3,0.4>$	$<(0.2,0.3,0.5,0.5); 0.4,0.5,0.3>$	$<(0.4,0.5,0.6,0.7); 0.4,0.2,0.3>$
A_3	$<(0.4,0.5,0.6,0.6); 0.8,0.3,0.4>$	$<(0.3,0.4,0.5,0.5); 0.3,0.4,0.5>$	$<(0.6,0.6,0.7,0.7); 0.2,0.3,0.1>$
A_4	$<(0.3,0.5,0.6,0.7); 0.7,0.4,0.5>$	$<(0.4,0.5,0.6,0.6); 0.4,0.4,0.3>$	$<(0.5,0.6,0.7,0.8); 0.5,0.1,0.2>$

Table 3. Decision matrix provided by an expert D^3

Alternatives	C_1	C_2	C_3
A_1	$<(0.4,0.5,0.6,0.6); 0.3,0.2,0.2>$	$<(0.4,0.5,0.5,0.5); 0.3,0.5,0.2>$	$<(0.2,0.3,0.4,0.4); 0.4,0.3,0.3>$
A_2	$<(0.5,0.6,0.6,0.7); 0.4,0.5,0.6>$	$<(0.3,0.5,0.5,0.6); 0.8,0.2,0.3>$	$<(0.3,0.4,0.4,0.5); 0.5,0.3,0.2>$
A_3	$<(0.6,0.7,0.7,0.8); 0.4,0.3,0.3>$	$<(0.6,0.6,0.6,0.7); 0.6,0.5,0.4>$	$<(0.4,0.5,0.6,0.6); 0.4,0.2,0.2>$
A_4	$<(0.5,0.5,0.7,0.7); 0.2,0.1,0.1>$	$<(0.5,0.5,0.6,0.8); 0.3,0.2,0.2>$	$<(0.3,0.5,0.5,0.7); 0.5,0.2,0.3>$

Step 1: Compute the normalized decision matrix
Since the given ratings are profit, we need not normalize the given decision matrix.

Step 2: Compute the aggregated neutrosophic decision matrix
Assume that the associated weighted vector $w = (0.067, 0.666, 0.267)^T$ which can be obtained by the fuzzy linguistic quantifier is "most" with the pair of $(\alpha, \beta) = (0.3, 0.8)$. To aggregate all experts' ratings for each alternative with respect to each attribute and the SVTNOWHA operator is used and the final aggregated values are given in Table 4.

Table 4. Individual overall attributes values

Alternatives	C_1	C_2	C_3
A_1	$<(0.409,0.51,0.575,0.61);0.3,0.4,0.2>$	$<(0.372,0.474,0.506,0.51);0.3,0.5,0.3>$	$<(0.205,0.308,0.409,0.477);0.3,0.4,0.3>$
A_2	$<(0.424,0.474,0.534,0.582);0.4,0.5,0.6>$	$<(0.205,0.308,0.424,0.429);0.4,0.5,0.5>$	$<(0.367,0.469,0.529,0.575);0.4,0.3,0.3>$
A_3	$<(0.409,0.477,0.575,0.61);0.4,0.3,0.4>$	$<(0.31,0.409,0.474,0.575);0.3,0.5,0.5>$	$<(0.225,0.36,0.394,0.477);0.2,0.3,0.2>$
A_4	$<(0.308,0.469,0.575,0.633);0.2,0.4,0.5>$	$<(0.319,0.424,0.474,0.61);0.3,0.4,0.3>$	$<(0.308,0.474,0.633,0.706);0.5,0.4,0.3>$

Step 3: Determine the single valued trapezoidal positive and negative ideal solutions.
The single valued trapezoidal neutrosophic positive and negative ideal solutions are defined as

$$\tilde{r}_j^{\,+} = \{\tilde{r}_1^+, \tilde{r}_2^+, \dots, \tilde{r}_n^+\}, j = 1,2,3$$
$$\tilde{r}_1^+ =< (0.424,0.51,0.575,0.633); 0.4,0.3,0.2 >$$
$$\tilde{r}_2^+ =< (0.372,0.474,0.507,0.61); 0.4,0.4,0.3 >$$
$$\tilde{r}_3^+ =< (0.367,0.469,0.633,0.706); 0.5,0.3,0.2 >$$

$$\tilde{r}_j^{\,-} = \{\tilde{r}_1^-, \tilde{r}_2^-, \dots, \tilde{r}_n^-\}, j = 1,2,3$$
$$\tilde{r}_1^- =< (0.308,0.469,0.534,0.583); 0.3,0.5,0.6 >$$
$$\tilde{r}_2^- =< (0.205,0.308,0.424,0.423); 0.3,0.5,0.5 >$$
$$\tilde{r}_3^- =< (0.205,0.308,0.394,0.477); 0.2,0.4,0.3 >$$

Step 4: Compute the separation distance measures.
Normalized hamming distance measure is used to find negative and positive separation measures d_i^+ and d_i^- of each alternative.

$$d_i^+ = \sum_{j=1}^{3} \omega_j d\left(\tilde{R}_{ij}, \tilde{r}_j^+\right) \text{ and } d_i^- = \sum_{j=1}^{3} \omega_j d\left(\tilde{R}_{ij}, \tilde{r}_j^-\right), i = 1,2,3,4$$

$$d_1^+ = 0.0701, d_2^+ = 0.0904, d_3^+ = 0.0758, d_4^+ = 0.0581$$
$$d_1^- = 0.0776, d_2^- = 0.0573, d_3^- = 0.0720, d_4^- = 0.0897$$

Step 5: Calculate the relative closeness coefficient (RCC) of each alternative

The RCC is calculated by using equation $R_i = \frac{d_i^-}{(d_i^+ + d_i^-)}, i = 1,2,3,4$

$$R_1 = \frac{d_1^-}{d_1^+ + d_1^-} = \frac{0.0776}{0.0701 + 0.0776} = 0.5256$$

$\Rightarrow R_1 = 0.5256$, $R_2 = 0.3882$, $R_3 = 0.4871$, $R_4 = 0.6070$

Step 6: Select the best alternative A_i

Rank all the alternatives A_i $(i = 1,2,3,4)$ according to the closeness coefficient R_i.

$$A_4 > A_1 > A_3 > A_2$$

Thus the most desirable alternative is food company (A_4).
The separation measure and the value of relative closeness coefficient (RCC) expressed in the following Figure 1.

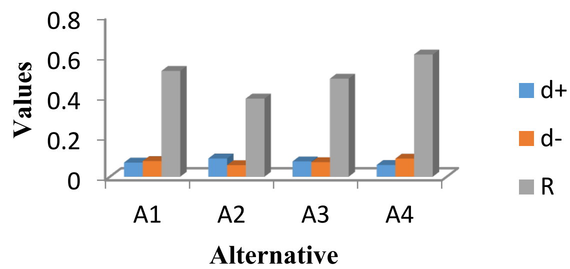

Figure1. Separation measure and the RCC for each Alternative

Results:
Three investment company intends to invest a sum of money have been selected under four attributes including computer company, arms company, car company and food company. The results indicate that the best Company is A_4 which has highest closeness coefficient value as shown in Figure 2.

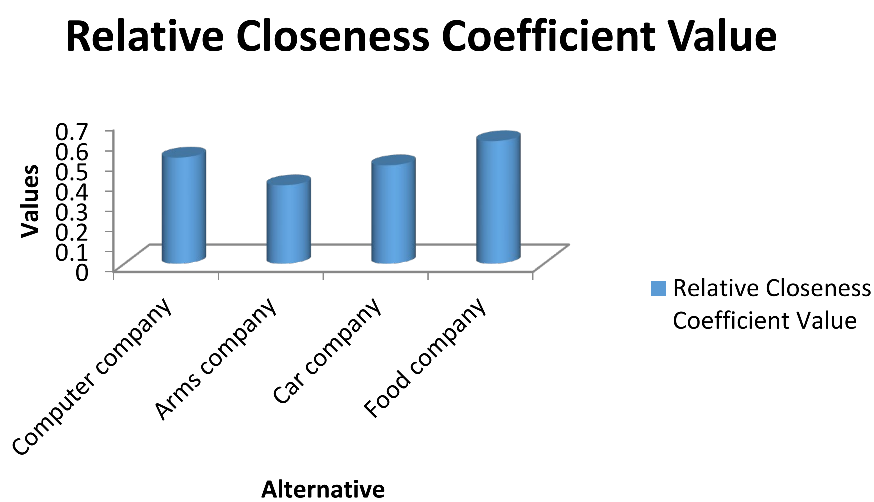

Figure 2. Rating values of alternatives

Comparative Analysis:
In this paper, point out the advantages of our proposed approach compared with some existing methods. First we compare our proposed approach with Jun Ye (2016), we have considered the same MADM problem under neutrosophic environment and obtained the similar ranking values and it can be consider arithmetic and geometric aggregation operators for solving MADM problems under neutrosophic environment. Similarly, consider our proposed approach compared with existing method Deli and Subas (2015) to deal with de-neutrosophication approach for solving MADM problems obtained similar ranking result. Further by comparing with the proposed SVTNOWHA – TOPSIS approach with existing methods such as TODIM (Pramanik and Mallick (2019)) and SVTNGOWHA operator (Paulraj and Tamilarasi (2022)), and find out the same alternative food company (A_4), which is the best one.

5. Conclusion

In this paper, the MADM problem attribute value in single valued trapezoidal neutrosophic numbers form has been investigated. Then a SVTNOWHA – TOPSIS method combined with SVTNOWHA operator and TOPSIS method are proposed. The SVTNOWHA – TOPSIS method procedure has been explained and the proposed method extended for solving MADM problems with single valued trapezoidal neutrosophic numbers. Finally, an example is illustrated in a case study of Investment Company when choosing an investment plan. In the future study, we aim to extend the proposed approach and applied for several examples such as information material, project selection and many other areas of decision making problems.

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