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A Novel Weighted Average Operator For Trapezoidal Intuitionistic Fuzzy Sets And Its Application To Multicriteria Decision Making Problems

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Abstract: Aggregation operations on fuzzy numbers are operations by which several fuzzy numbers are combined to produce a single fuzzy number. The aim of this paper is to introduce a novel weighted average operator on trapezoidal intuitionistic fuzzy numbers and study their aggregation properties. Finally, we give an application of the proposed weighted average operator to multi-criteria decision making problem based on trapezoidal intuitionistic fuzzy sets.

Keywords —Weighted average operator, Intuitionistic fuzzy numbers, Interval valued intuitonistic fuzzy number, Trapezoidal intuitionistic fuzzy numbers, Multi-criteria decision making problem, Accuracy function.

I. Introduction

Attanassov proposed the concept of intuitionistic fuzzy sets (IFSs) and interval valued intuitionistic fuzzy sets (IVIFSs). Nehi and Melki [7] have introduced the concept of trapezoidal intuitionistic fuzzy sets (TrIFN) which is the extension of triangular fuzzy sets. Furthermore, Lakshmana [5] developed a TrIFN with some additional conditions.

Xu [9] introduced the concept of some geometric aggregation operators for intuitionistic fuzzy number. He has also proposed weighted arithmetic average operator and weighted geometric average operator to aggregate the performances of alternative with respect to criteria. Weighted arithmetic average operator and weighted geometric average operator are two common aggregation operators in the field of information system. Multi criteria decision making problem (MCDM) [2, 3, 6] utilizes the accuracy functions to rank the alternatives. Some authors have noticed the advantage of TrIFNs in MCDM problem [8-10].

The approach of this paper is coordinated as follows: The necessary basic definitions are briefly introduced in section 2. In section 3, novel weighted average operator on TrIFNs is introduced and some properties on TrIFNs are studied. In section 4, a new method for solving MCDM problem is presented by using the proposed weighted average operator. In section 5, conclusion and future scope are given.

II. Preliminaries

Definition 2.1. [1] An IFS A of a non empty set X is defined as $A_1 = \left\{\left(x, \mu_{A_1}(x), \nu_{A_1}(x)\right)/x \in X\right\}$ where $\mu_{A_1}: X \to [0,1]$ and $\nu_{A_1}: X \to [0,1]$ defines the degree of membership $\mu_{A_1}(x)$ and degree of membership $\nu_{A_1}(x)$ of x in X to lie in A, such that, $0 \le \mu_{A_1}(x) + \nu_{A_1}(x) \le 1$.

Definition 2.2. [7] Let $A = ([a_{\mu 1}, b_{\mu 1}, c_{\mu 1}, d_{\mu 1}],$ $[e_{\nu 1}, f_{\nu 1}, g_{\nu 1}, h_{\nu 1}])$, (where $e_{\nu 1} \le a_{\mu 1}, f_{\nu 1} \le b_{\mu 1} \le c_{\mu 1} \le g_{\nu 1}, d_{\mu 1} \le h_{\nu 1}$) be a TrIFN. Then the degree of acceptance and degree of rejection functions are defined as

$$\mu_{A(x)} = \begin{cases} \dfrac{x - a_{\mu 1}}{b_{\mu 1} - a_{\mu 1}} & ;\ a_{\mu 1} \le x \le b_{\mu 1} \\ 1 & ;\ b_{\mu 1} \le x \le c_{\mu 1} \\ \dfrac{x - d_{\mu 1}}{c_{\mu 1} - d_{\mu 1}} & ;\ c_{\mu 1} \le x \le d_{\mu 1} \\ 0 & ;\quad otherwise \end{cases}$$

$$\nu_{A(x)} = \begin{cases} \frac{x - f_{\nu 1}}{e_{\nu 1} - f_{\nu 1}} & ;\ e_{\nu 1} \le x \le f_{\nu 1} \\ 0 & ;\ f_{\nu 1} \le x \le g_{\nu 1} \\ \frac{x - g_{\nu 1}}{h_{\nu 1} - g_{\nu 1}} & ;\ g_{\nu 1} \le x \le h_{\nu 1} \\ 1 & ;\quad otherwise \end{cases}$$

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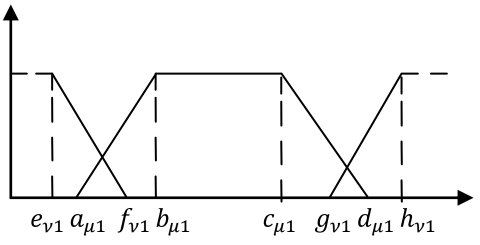
The graphical representation of TrIFN is shown below



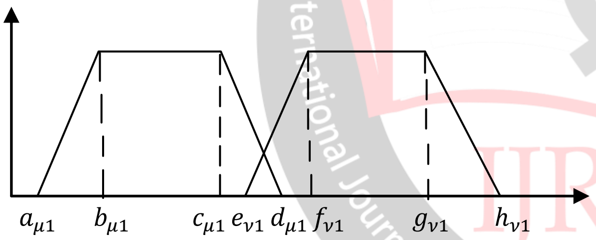
(fig.1)

Definition 2.3. [5] Let $A = ([a_{\mu 1}, b_{\mu 1}, c_{\mu 1}, d_{\mu 1}], [e_{\nu 1}, f_{\nu 1}, g_{\nu 1}, h_{\nu 1}])$, (where $e_{\nu 1} \geq c_{\mu 1}$ and $f_{\nu 1} \geq d_{\mu 1}$ (or) $g_{\nu 1} \leq a_{\mu 1}$and $h_{\nu 1} \leq b_{\mu 1}$) be a TrIFN. Then the degree of acceptance and degree of rejection functions are defined as

$$\mu_{A(x)} = \begin{cases} \dfrac{x - a_{\mu 1}}{b_{\mu 1} - a_{\mu 1}} & ;\ a_{\mu 1} \leq x \leq b_{\mu 1} \\ 1 & ;\ b_{\mu 1} \leq x \leq c_{\mu 1} \\ \dfrac{x - d_{\mu 1}}{c_{\mu 1} - d_{\mu 1}} & ;\ c_{\mu 1} \leq x \leq d_{\mu 1} \\ 0 & ;\quad otherwise \end{cases}$$

$$\nu_{A(x)} = \begin{cases} \dfrac{x - e_{\nu 1}}{f_{\nu 1} - e_{\nu 1}} & ;\ e_{\nu 1} \leq x \leq f_{\nu 1} \\ 1 & ;\ f_{\nu 1} \leq x \leq g_{\nu 1} \\ \dfrac{x - h_{\nu 1}}{g_{\nu 1} - h_{\nu 1}} & ;\ g_{\nu 1} \leq x \leq h_{\nu 1} \\ 0 & ;\ otherwise \end{cases}$$

The graphical representation of TrIFN is shown below



(fig.2)

Definition 2.4. [5] Let $A = ([a_{\mu 1}, b_{\mu 1}, c_{\mu 1}, d_{\mu 1}], [e_{\nu 1}, f_{\nu 1}, g_{\nu 1}, h_{\nu 1}])$, be a TrIFN, (where $e_{\nu 1} \geq c_{\mu 1}$ and $f_{\nu 1} \geq d_{\mu 1}$ (or) $g_{\nu 1} \leq a_{\mu 1}$ and $h_{\nu 1} \leq b_{\mu 1}$) and throughout this paper we have taken as $e_{\nu 1} \geq c_{\mu 1}$ and $f_{\nu 1} \geq d_{\mu 1}$. The same proof is also applicable for $g_{\nu 1} \leq a_{\mu 1}$ and $h_{\nu 1} \leq b_{\mu 1}$.

Definition 2.5.[7] Let $A = ([a_{\mu 1}, b_{\mu 1}, c_{\mu 1}, d_{\mu 1}], [e_{\nu 1}, f_{\nu 1}, g_{\nu 1}, h_{\nu 1}])$, $B = ([a_{\mu 2}, b_{\mu 2}, c_{\mu 2}, d_{\mu 2}], [e_{\nu 2}, f_{\nu 2}, g_{\nu 2}, h_{\nu 2}])$, be a TrIFN. Then

1. $A + B = \begin{pmatrix} [a_{\mu 1} + a_{\mu 2}, b_{\mu 1} + b_{\mu 2}, c_{\mu 1} + c_{\mu 2}, d_{\mu 1} + d_{\mu 2}], \\ [e_{\nu 1} + e_{\nu 2}, f_{\nu 1} + f_{\nu 2}, g_{\nu 1} + g_{\nu 2}, h_{\nu 1} + h_{\nu 2}] \end{pmatrix}.$
2. $A * B = \begin{pmatrix} [a_{\mu 1}a_{\mu 2}, b_{\mu 1}b_{\mu 2}, c_{\mu 1}c_{\mu 2}, d_{\mu 1}d_{\mu 2}], \\ [e_{\nu 1}e_{\nu 2}, f_{\nu 1}f_{\nu 2}, g_{\nu 1}g_{\nu 2}, h_{\nu 1}h_{\nu 2}] \end{pmatrix}.$
3. $\lambda A = ([\lambda a_{\mu 1}, \lambda b_{\mu 1}, \lambda c_{\mu 1}, \lambda d_{\mu 1}], [\lambda e_{\nu 1}, \lambda f_{\nu 1}, \lambda g_{\nu 1}, \lambda f_{\nu 1}])$.

Definition 2.6. [4] Aggregations operations on fuzzy sets are operations by which several fuzzy sets are combined to produce a single set. In general any aggregation operation is defined by a function

$$h: [0,1]^n \to [0,1]$$

for some, $n \geq 2$ when applied to n fuzzy sets $A_1, A_2, \dots, A_n$ defined on X, h produces an aggregate fuzzy set A by operating on the membership grades of each $x \in X$ in the aggregated sets. Thus,

$$\mu_A(x) = h(\mu_{A_1}(x), \mu_{A_2}(x), \dots, \mu_{A_n}(x))$$

In order to qualify as an aggregation function, h must satisfy at least the following three axiomatic requirements.

(P1. Boundary conditions) $h(0,0,\dots,0) = 0$ and $h(1,1,\dots,1) = 1$.

(P2. Monotonicity) For any pair $a_1, a_2, \dots, a_n$ and $b_1, b_2, \dots, b_n$ of n tuples such that $a_i, b_i \in [0,1]$ for all $i \in \mathbb{N}_n$, then

$$h(a_1, a_2, \dots, a_n) \leq h(b_1, b_2, \dots, b_n).$$

(P3. Continuous) h is a continuous function.

(P4. Symmetric) h is a symmetric function in all its argument,

$$h(a_1, a_2, \dots, a_n) = h(b_1, b_2, \dots, b_n).$$

for any permutation p on $\mathbb{N}_n$.

(P5. Idempotent) h is an idempotent function, $h(a, a, \dots, a) = a$, for all $a \in [0,1]$.

Definition 2.7. [11] Let $Q = ([a_{\mu 1}, b_{\mu 1}, c_{\mu 1}, d_{\mu 1}], [e_{\nu 1}, f_{\nu 1}, g_{\nu 1}, h_{\nu 1}])$ be a TrIFNs. Then the score function on a TrIFN can be defined by $H(Q) = (a_{\mu 1} + b_{\mu 1} + c_{\mu 1} + d_{\mu 1})/4 - (e_{\nu 1} + f_{\nu 1} + g_{\nu 1} + h_{\nu 1})/4$, $H(Q) \in [-1, 1]$.

III. A NOVEL WEIGHTED AVERAGE OPERATOR ON TRIFN

Definition 3.1. Let $A_i = ([a_{\mu i}, b_{\mu i}, c_{\mu i}, d_{\mu i}], [e_{\nu i}, f_{\nu i}, g_{\nu i}, h_{\nu i}]) \in TrIFNs$ as in fig. 2. The weighted average operator $H_j(A_1, A_2, \dots, A_n) =$

$$\left(\left[\sum_{i=1}^{n} w_i a_{\mu i}, \sum_{i=1}^{n} w_i b_{\mu i}, \sum_{i=1}^{n} w_i c_{\mu i}, \sum_{i=1}^{n} w_i d_{\mu i} \right], \left[\sum_{i=1}^{n} w_i e_{\nu i}, \sum_{i=1}^{n} w_i f_{\nu i}, \sum_{i=1}^{n} w_i g_{\nu i}, \sum_{i=1}^{n} w_i h_{\nu i} \right] \right),$$

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where $\sum_{i=1}^{n} w_i c_{\mu i} \leq \sum_{i=1}^{n} w_i e_{\nu i}$ and $\sum_{i=1}^{n} w_i d_{\mu i} \leq \sum_{i=1}^{n} w_i f_{\nu i}$. w_i are weights of $A_i (i = 1, 2, \dots, n), w_i \in [0, 1]$ and $\sum_{i=1}^{n} w_i = 1$.

Theorem 3.2. Let $A_i = ([a_{\mu i}, b_{\mu i}, c_{\mu i}, d_{\mu i}], [e_{\nu i}, f_{\nu i}, g_{\nu i}, h_{\nu i}])$, (where $e_{\nu i} \geq c_{\mu i}$ and $f_{\nu i} \geq d_{\mu i}$) be a collection of TrIFNs. Then their aggregated value using the novel trapezoidal weighted average operator is also a TrIFNs.

Proof: W.K.T $A_i = ([a_{\mu i}, b_{\mu i}, c_{\mu i}, d_{\mu i}], [e_{\nu i}, f_{\nu i}, g_{\nu i}, h_{\nu i}])$, be a collection of TrIFN, where, $e_{\nu i} \geq c_{\mu i}$ and $f_{\nu i} \geq d_{\mu i}$,

$w_i A_i = ([w_i a_{\mu i}, w_i b_{\mu i}, w_i c_{\mu i}, w_i d_{\mu i}],$
$[w_i e_{\nu i}, w_i f_{\nu i}, w_i g_{\nu i}, w_i h_{\nu i}])$,
where, $w_i e_{\nu i} \geq w_i c_{\mu i}$ and $w_i f_{\nu i} \geq w_i d_{\mu i}$.

$\sum w_i A_i = ([\sum w_i a_{\mu i}, \sum w_i b_{\mu i}, \sum w_i c_{\mu i}, \sum w_i d_{\mu i}],$
$[\sum w_i e_{\nu i}, \sum w_i f_{\nu i}, \sum w_i g_{\nu i}, \sum w_i h_{\nu i}])$,
Since, $w_i c_{\mu i} \leq w_i e_{\nu i}$ and $w_i d_{\mu i} \leq w_i f_{\nu i}$,
$\sum_{i=1}^{n} w_i c_{\mu i} \leq \sum_{i=1}^{n} w_i e_{\nu i}$ and $\sum_{i=1}^{n} w_i d_{\mu i} \leq \sum_{i=1}^{n} w_i f_{\nu i}$.

Hence, $\sum w_i A_i$ is a TrIFNs.

A novel weighted average operator has the following properties.

Theorem 3.3. ($P1$. Idempotency):
Let $A_i = ([a_{\mu i}, b_{\mu i}, c_{\mu i}, d_{\mu i}], [e_{\nu i}, f_{\nu i}, g_{\nu i}, h_{\nu i}])$, $(i = 1, 2, \dots, n)$ be a collection of TrIFNs. If each A_i $(i = 1, 2, \dots, n)$ is equal to A. Then $H_j(A_1, A_2, \dots, A_n) = A$.

(P2. Boundedness):
Let $A_i = ([a_{\mu i}, b_{\mu i}, c_{\mu i}, d_{\mu i}], [e_{\nu i}, f_{\nu i}, g_{\nu i}, h_{\nu i}])$, $(i = 1, 2, \dots, n)$ be a collection of TrIFNs.

Let $A^- = ([\min a_{\mu i}, \min b_{\mu i}, \min c_{\mu i}, \min d_{\mu i}],$
$[\max e_{\nu i}, \max f_{\nu i}, \max g_{\nu i}, \max \mathrm{h}_{\nu i}])$,

$A^+ = ([\max a_{\mu i}, \max b_{\mu i}, \max c_{\mu i}, \max d_{\mu i}],$
$[\min e_{\nu i}, \min f_{\nu i}, \min g_{\nu i}, \min \mathrm{h}_{\nu i}])$.
Then $A^- \leq H_j(A_1, A_2, \dots, A_n) \leq A^+$.

($P3$. Monotonicity): $A_i (i = 1, 2, \dots, n)$ and A_i^* $(i = 1, 2, \dots, n)$ be the collection of TrIFNs.
If $A_i \leq A_i^* (i = 1, 2, \dots, n)$ then $H_j(A_1, A_2, \dots, A_n) \leq H_j(A_1^*, A_2^*, \dots, A_n^*)$.

Proof: $(P1)$ Since $A_i = A$ for $(i = 1, 2, \dots, n)$, we have $H_j(A_1, A_2, \dots, A_n) = w_1 A_1 + w_2 A_2 +, \dots, + w_n A_n = \sum_{i=1}^{n} w_i A_i = A \sum_{i=1}^{n} w_i = A$.

$(P2)$ Since $A^- \leq A_i \leq A^+$ for $(i = 1, 2, \dots, n)$, we have $\sum_{i=1}^{n} w_i A^- \leq \sum_{i=1}^{n} w_i A_i \leq \sum_{i=1}^{n} w_i A^+$. Hence $A^- \leq \sum_{i=1}^{n} w_i A_i \leq A^+$.(using (P1)),
$\Rightarrow$ $A^- \leq H_j(A_1, A_2, \dots, A_n) \leq A^+$.

$(P3)$ Since $A_i \leq A_i^*$ for $(i = 1, 2, \dots, n) \Rightarrow \sum_{i=1}^{n} w_i A_i \leq \sum_{i=1}^{n} w_i A_i^* \Rightarrow H_j(A_1, A_2, \dots, A_n) \leq H_j(A_1^*, A_2^*, \dots, A_n^*)$.
Thus we complete the proofs of these properties.

IV. Application of the Proposed Weighted Average Operator in Multi-Criteria Decision-Making Problem

A fuzzy MCDM problem with weights is given in this section. Let the set of alternatives be $S = \{S_1, S_2, \dots, S_m\}$ and let the corresponding weights of the criteria $Z_1, Z_2, \dots, Z_n$ be $w_1, w_2, \dots, w_n$, $\sum w_i = 1$. Let the performance of alternative S_i be the TrIFN $H_j(A_1, A_2, \dots, A_n) = ([\sum w_i a_{\mu i}, \sum w_i b_{\mu i}, \sum w_i c_{\mu i}, \sum w_i d_{\mu i}], [\sum w_i e_{\nu i}, \sum w_i f_{\nu i}, \sum w_i g_{\nu i}, \sum w_i h_{\nu i}])$, w_i are weights of $A_i (i = 1, 2, \dots, n), w_i \in [0, 1]$ and $\sum w_i = 1$.

The above TrIFN is denoted by $Q_i = ([a_{\mu i}^*, b_{\mu i}^*, c_{\mu i}^*, d_{\mu i}^*], [e_{\nu i}^*, f_{\nu i}^*, g_{\nu i}^*, h_{\nu i}^*])$, where the alternative S_i satisfies the criterion Z_j with degree $[a_{\mu i}^*, b_{\mu i}^*, c_{\mu i}^*, d_{\mu i}^*]$ and the alternative S_i does not satisfy the criterion Z_j at with degree $[e_{\nu i}^*, f_{\nu i}^*, g_{\nu i}^*, h_{\nu i}^*]$ as given by the decision maker.

We obtain the aggregating TrIFN Q_i for S_i $(i = 1,2, \dots, m)$ as $Q_i = ([a_{\mu i}^*, b_{\mu i}^*, c_{\mu i}^*, d_{\mu i}^*], [e_{\nu i}^*, f_{\nu i}^*, g_{\nu i}^*, h_{\nu i}^*])$. Then we can apply the Score function to Q_i. Finally we rank the alternatives $S_i (i = 1, 2, \dots, m)$ choose the best one according to $H(Q)$.

4.1 Illustrative example

Now a numerical illustration of the MCDM methodology is given.

Example: The four commercial non-linear programming software packages (alternatives) are evaluated with respect to the following three criteria Z_1 is the cost; (2). Z_2 is the ease of use; (3). Z_3 is the editing facilities. Four possible alternatives are to be evaluated using the TrIFNs by the decision maker under the above three criteria as listed in the below (Table 1) decision matrix.

Assuming the weights of $Z_1, Z_2$and Z_3 as 0.40,0.35 and 0.25, we obtain the novel weighted average for TrIFN S_i $(i = 1,2,3,4)$ using definition (2.7) as follows

$$Q_1 = [(0.0590, 0.1450, 0.2150, 0.2650),$$
$$(0.3150, 0.3650, 0.4150, 0.4650)]$$
$$Q_2 = [0.1050, 0.1725, 0.2400, 0.2900,$$

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$$(0.3400,0.3900,0.4600,0.5475)]$$
$$Q_3 = [(0.1175,0.1675,0.2350,0.2850), (0.3475,0.4175,0.4675,0.5350)]$$
$$Q_4 = [(0.1250,0.1925,0.2550,0.3050), (0.3550,0.4425,0.5125,0.5825)].$$

$H\ (Q_i\ ), (i = 1,2,3,4)$ as follows
$H\ (Q_1) = -0.2190, H\ (Q_2) = -0.2325,$
$H\ (Q_3) = -\ 0.2406, H\ (Q_4\ ) = -0.2537.$

Therefore we get, $S_1 > S_2 > S_3 > S_4$. Hence S_1 is the most desirable alternative.

Table 1: Decision matrix

	Z_1	Z_2	Z_3
S_1	$[(0.01,0.15,0.25,0.3), (0.35,0.4,0.45,0.5)]$	$[(0.05,0.1,0.15,0.2), (0.25,0.3,0.35,0.4)]$	$[(0.15,0.2,0.25,0.3), (0.35,0.4,0.45,0.5)]$
S_2	$[(0.05,0.1,0.15,0.2), (0.25,0.3,0.4,0.5)]$	$[(0.1,0.2,0.3,0.35), (0.4,0.45,0.5,0.6)]$	$[(0.2,0.25,0.3,0.35), (0.4,0.45,0.5,0.55)]$
S_3	$[(0.1,0.15,0.2,0.25), (0.3,0.4,0.45,0.5)]$	$[(0.15,0.2,0.3,0.35), (0.4,0.45,0.5,0.6)]$	$[(0.1,0.15,0.2,0.25), (0.35,0.4,0.45,0.5)]$
S_4	$[(0.1,0.15,0.2,0.25), (0.3,0.4,0.5,0.6)]$	$[(0.1,0.2,0.25,0.3), (0.35,0.45,0.5,0.55)]$	$[(0.2,0.25,0.35,0.4), (0.45,0.5,0.55,0.6)]$

V. CONCLUSION AND FUTURE SCOPE

A new class of IFNs was defined in [5], which practically helps in gathering data rather than the classical IFNs. In this paper we have introduced an operator to aggregate such data in the form of TrIFN. The operator defined in this paper is also applied to a MCDM problem. This novel weighted average operator will help us to solve practical problems with data which are conveniently collected from experts.

The proposed novel weighted average operator on TrIFNs can be extended to any IFNs and hence MCDM problems involving IFNs can be solved.

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