Hesitant Fuzzy tautological sets

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Abstract: In this paper, I study some properties of Hesitant Fuzzy Tautological Sets using Hesitant fuzzy implication operator.

Keywords: Hesitant fuzzy sets (HFS), Hesitant fuzzy implication operator (HFIO) and Hesitant fuzzy tautological sets (HFTS).

1. Introduction:

A phenomenal set theory named and introduced by Zadeh [8] several extensions of this concept have been defined. Atanassov [1] has given idea about intuitionistic fuzzy sets. Hiroshi Hashimoto [2,3] used ←,↼ operators in fuzzy matrices and obtained some results. Sriram and Murugadas [6] applied this ← operator to IFM and studied about *g*-inverse and sub-inverse of IFMs. Murugadas and Lalitha [4] obtained some relations between the operators ←and↼.ViceneTorra [7] used the envelope of the hesitant fuzzy sets are an intuitionistic fuzzy sets.The authors [5] proved some results for implication operator on intuitionistic fuzzy Tautological Matrix. In this paper,We use → operator in HFS and study some properties of Hesitant fuzzy Tautological sets.

2. Preliminaries

Definition 2.1. Intuitionistic Fuzzy Sets Given a reference set χ, an intuitionistic fuzzy set (or IFS) A on χ is represented in terms of two functions $\mu : \chi \to [0,1]$ and $\gamma : \chi \to [0,1]$ such that $0 \leq \mu(x) + \gamma(x) \leq 1$ for all $x \in \chi$.

Where μ represents the degree of membership and γ the degree of non-membership of x into the set A. Ifs are often represented as follows:

$< x, \mu_A, \gamma_A >$ for $x \in \chi$

Given two IFS A and B represented by the functions μ_A, γ_A, μ_B and γ_B following operations have been defined.

- Complement

  $A^C = \{\langle x, \gamma_A(x), \mu_A(x)\rangle\}$

- Union

  $A \cup B = \{\langle x, \max(\mu_A(x), \mu_B(x)), \min(\gamma_A(x), \gamma_B(x))\rangle\}$

- Intersection

  $A \cap B = \{\langle x, \min(\mu_A(x), \mu_B(x)), \max(\gamma_A(x), \gamma_B(x))\rangle\}$

- $\oplus$ -union

  $A \oplus B = \{\langle x, \mu_A(x) + \mu_B(x) - \mu_A(x)\mu_B(x), (\gamma_A(x)\gamma_B(x)\rangle\}$

- ⊗-intersection

$$A \otimes B = \{\langle x, \mu_A(x)\,\mu_B(x), \gamma_A(x) + \gamma_B(x) - \gamma_A(x)\,\gamma_B(x)\rangle\}$$

Definition 2.2. Hesitant Fuzzy Sets Let χ be a reference set, then we define hesitant fuzzy set on χ in terms of a function h that when applied to χ returns a subset of [0,1].

Given a hesitant fuzzy set h, we define below its lower and upper bound,

- lower bound: $h^-(x) = \min h(x)$ and
- upper bound: $h^+(x) = \max h(x)$.

It is clear that given a hesitant fuzzy set h, the pair of functions $h^-, 1 - h^+$ define an intuitionistic fuzzy set.

Definition 2.3. Given a hesitant fuzzy set represented by its membership function h, we define its complement as follows:

$$h^c(x) = \bigcup_{\gamma \in h(x)} \{1 - \gamma\}$$

Definition 2.4. Given a hesitant fuzzy set h, we define the intuitionistic fuzzy set $A_{env}(h)$ as the envelope of h. This set, which will be denoted by $A_{env}(h)$, is represented by $\{\langle x, \mu_A(x), \gamma_A(x)\rangle\}$ with μ and γ defined as follows:

- $\mu(x) = h^-(x)$
- $\gamma(x) = 1 - h^+(x)$

3. Results on HFTSs

Definition 3.1. An Hesitant fuzzy set is called an Hesitant fuzzy tautological set (HFTS) if and only if $h_1^- \geq 1 - h_1^+$.

Definition3.2. For $h^-(x)$, $1-h^+(x) \in x$, define

$$h^-(x) \rightarrow 1 - h^+(x) = 1 - h^+(x) \leftarrow h^-(x) = \begin{cases} <1,0>, & if\ h^-(x) \leq 1 - h^+(x) \\ 1 - h^+(x), & h^-(x) \geq 1 - h^+(x) \end{cases}$$

Property 3.1. Let $A(h_1)$ and $A(h_2)$ be two HFSs then the following expressions are HFTSs.

1. $A_{env}(h_1) \rightarrow A_{env}(h_1)$
2. $\bar{A}_{env}(h_1) \rightarrow A_{env}(h_1)$
3. $A_{env}(h_1) \rightarrow (A_{env}(h_2) \rightarrow A_{env}(h_1))$

Proof:

1. Let $A_{env}(h_1) = \langle h_1^-, 1-h_1^+\rangle$

   $As\ \langle h_1^-, 1 - h_1^+\rangle = \langle h_1^-, 1-h_1^+\rangle$

   Then $\langle h_1^-, 1 - h_1^+\rangle = \langle h_1^-, 1-h_1^+\rangle = \langle 1,0\rangle$

   So $A_{env}(h_1) \rightarrow A_{env}(h_2)$ is an HFTSs

2. $A_{env}(h_1) = \langle h_1^-, 1-h_1^+\rangle$

   $\bar{A}_{env}(h_1) = \langle 1-h_1^+, h_1^-\rangle$

   If $\langle 1-h_1^+, h_1^-\rangle \leq \langle h_1^-, 1-h_1^+\rangle$

   Then $\bar{A}_{env}(h_1) \rightarrow A_{env}(h_1) = \langle 1,0\rangle$

3. Let $A_{env}(h_1) = \langle h_1^-, 1\text{-}h_1^+\rangle$, $A_{env}(h_2) = \langle h_2^-, 1\text{-}h_2^+\rangle$

Then $A_{env}(h_2) \to A_{env}(h_1) = \langle h_2^-, 1\text{-}h_2^+\rangle \to \langle h_1^-, 1\text{-}h_1^+\rangle$

Case(i)

If $\langle h_2^-, 1\text{-}h_2^+\rangle \le \langle h_1^-, 1\text{-}h_1^+\rangle$, then

$\langle h_2^-, 1\text{-}h_2^+\rangle \to \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1,0\rangle$

$A_{env}(h_2) \to A_{env}(h_1) = \langle 1,0\rangle$

$A_{env}(h_1) \to (A_{env}(h_2) \to A_{env}(h_1)) = A_{env}(h_1) = \langle 1, 0\rangle$

$= \langle h_1^-, 1\text{-}h_1^+\rangle \to \langle 1, 0\rangle = \langle 1, 0\rangle$

Case (ii)

$\langle h_2^-, 1\text{-}h_2^+\rangle > \langle h_1^-, 1\text{-}h_1^+\rangle$ then

$\langle h_2^-, 1\text{-}h_2^+\rangle \to \langle h_1^-, 1\text{-}h_1^+\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle$

$A_{env}(h_2) \to A_{env}(h_1)$ c

$A_{env}(h_1) \to (A_{env}(h_2) \to A_{env}(h_1)) = A_{env}(h_1) \to \langle h_1^-, 1\text{-}h_1^+\rangle$

$= \langle h_1^-, 1\text{-}h_1^+\rangle \to \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

Thus $A_{env}(h_1) \to (A_{env}(h_2) \to A_{env}(h_1))$ is an HFTSs.

Property 3.2. If $A_{env}(h_1)$ and $A_{env}(h_2)$ be to HFTSs then

1. $A_{env}(h_1) \to (A_{env}(h_1) \vee A_{env}(h_2))$
2. $A_{env}(h_2) \to (A_{env}(h_1) \vee A_{env}(h_2))$
3. $A_{env}(h_1) \to A_{env}(h_2) \to (A_{env}(h_1) \wedge A_{env}(h_2))$ are HFTSs.

Proof

$$(A_{env}(h_1) \vee A_{env}(h_2)) = \langle h_1^-, 1\text{-}h_1^+\rangle \vee \langle h_2^-, 1\text{-}h_2^+\rangle$$

Case (i)

If $\langle h_1^-, 1\text{-}h_1^+\rangle \le \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \to (A_{env}(h_1) \vee A_{env}(h_2)) = A_{env}(h_1) \to \langle h_2^-, 1\text{-}h_2^+\rangle$

$= \langle h_1^-, 1\text{-}h_1^+\rangle \to \langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_1^+\rangle > \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \to (A_{env}(h_1) \vee A_{env}(h_2)) = A_{env}(h_1) \to \langle h_1^-, 1\text{-}h_1^+\rangle$

$= \langle h_1^-, 1\text{-}h_1^+\rangle \to \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

So, $A_{env}(h_1) \to (A_{env}(h_1) \vee A_{env}(h_2))$ is an HFTSs.

2. $A_{env}(h_2) \to (A_{env}(h_1) \vee A_{env}(h_2))$

Case (i)

If $\langle h_1^-, 1\text{-}h_1^+\rangle \le \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_2) \to \langle h_2^-, 1\text{-}h_2^+\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle \to \langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

Case (ii)

$\langle h_1^-, 1\text{-}h_1^+\rangle > \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_2) \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

So, $A_{env}(h_2) \rightarrow (A_{env}(h_1) \vee A_{env}(h_2))$ is an HFTSs.

3. $A_{env}(h_1) \rightarrow A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2))$

Case (i)

If $\langle h_1^-, 1\text{-}h_1^+\rangle \leq \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2) = A_{env}(h_2) \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle$

$= \langle h_2^-, 1\text{-}h_2^+\rangle \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle$

$A_{env}(h_1) \rightarrow A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2))$

$A_{env}(h_1) \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_1^+\rangle > \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2)) = A_{env}(h_2) \rightarrow \langle h_2^-, 1\text{-}h_2^+\rangle$

$= \langle h_2^-, 1\text{-}h_2^+\rangle \rightarrow \langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

$A_{env}(h_1) \rightarrow A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2)) = A_{env}(h_1) \rightarrow \langle 1, 0\rangle$

$= \langle h_1^-, 1\text{-}h_1^+\rangle \rightarrow \langle 1, 0\rangle \rightarrow \langle 1, 0\rangle$

So, $A_{env}(h_1) \rightarrow A_{env}(h_2) \rightarrow (A_{env}(h_1) \wedge A_{env}(h_2))$ is an HFTSs.

Property 3.3. If $A_{env}(h_1)$ and $A_{env}(h_2)$ are HFTSs then

(i) $A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_1)$

(ii) $A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_2)$ are HFTSs.

Proof:

(i) $A_{env}(h_1) \wedge A_{env}(h_2) = \langle h_1^-, 1\text{-}h_1^+\rangle \wedge \langle h_2^-, 1\text{-}h_2^+\rangle$

Case (i)

If $\langle h_1^-, 1\text{-}h_1^+\rangle \leq \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_1) = \langle h_1^-, 1\text{-}h_1^+\rangle \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_1^+\rangle > \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_1) = \langle h_2^-, 1\text{-}h_2^+\rangle \rightarrow \langle h_1^-, 1\text{-}h_1^+\rangle = \langle 1, 0\rangle$

Hence $A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_1)$ is an HFTSs.

(ii) $A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_2)$

Case (i)

If $\langle h_1^-, 1\text{-}h_1^+\rangle \leq \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_2) = \langle h_1^-, 1\text{-}h_1^+\rangle \rightarrow \langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_1^+\rangle > \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_2) = \langle h_2^-, 1\text{-}h_2^+\rangle \rightarrow \langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

Hence $A_{env}(h_1) \wedge A_{env}(h_2) \rightarrow A_{env}(h_2)$ is an HFTSs.

Property 3.4. If A_{env} (h_1) and A_{env} (h_2) are HFTSs and A_{env} (h_1)<A_{env} (h_2) thenA_{env} (h_1)→A_{env} (h_2) is an HFTSs.

Proof

Given A_{env} (h_1)<A_{env} (h_2) →⟨h_1^-, 1-h_1^+⟩<⟨h_2^-, 1-h_2^+⟩

Then A_{env} (h_1)<A_{env} (h_2) = ⟨1, 0⟩

So A_{env} (h_1)<A_{env} (h_2) is anHFTSs.

Property 3.5. If A_{env} (h_1),A_{env} (h_2) are HFTSs then the following expressions are HFTSs.

1. (A_{env} (h_1)∧A_{env} (h_1)→A_{env} (h_2))→A_{env} (h_2)
2. A_{env} (h_1)→(((A_{env} (h_1)) ←A_{env} (h_2)) ∨A_{env} (h_2))
3. A_{env} (h_2)→((A_{env} (h_1)→A_{env} (h_2))∨A_{env} (h_1))
4. A_{env} (h_2)→((A_{env} (h_1)∨A_{env} (h_2))→A_{env} (h_2))

Proof:

1. **Case(i)**

If ⟨h_1^-, 1-h_1^+⟩≤⟨h_2^-, 1-h_2^+⟩

A_{env} (h_1) →A_{env} (h_2) =⟨h_1^-, 1-h_1^+⟩→⟨h_2^-, 1-h_2^+⟩ = ⟨1, 0⟩

(A_{env} (h_1) ∧ (A_{env} (h_1) →A_{env} (h_2))) =⟨h_1^-, 1-h_1^+⟩∧⟨1, 0⟩ = ⟨1, 0⟩

(A_{env} (h_1) ∧ (A_{env} (h_1) →A_{env} (h_2)))→A_{env} (h_2)=⟨h_1^-, 1-h_1^+⟩→⟨h_2^-, 1-h_2^+⟩

= ⟨1, 0⟩

Case(ii)

If ⟨h_1^-, 1-h_1^+⟩≤⟨h_2^-, 1-h_2^+⟩

A_{env} (h_1) →A_{env} (h_2) =⟨h_1^-, 1-h_1^+⟩

A_{env} (h_1) ∧ (A_{env} (h_1)→A_{env} (h_2))=A_{env} (h_1) ∧⟨h_2^-, 1-h_2^+⟩

= ⟨h_1^-, 1-h_1^+⟩∧⟨h_2^-, 1-h_2^+⟩

= ⟨h_2^-, 1-h_2^+⟩

(A_{env} (h_1) ∧ (A_{env} (h_1)→A_{env} (h_2)))A_{env} (h_2)=⟨h_2^-, 1-h_2^+⟩→A_{env} (h_2)

= ⟨$h_2^-, 1 - h_2^+$⟩→⟨$h_2^-, 1 - h_2^+$⟩= ⟨1, 0⟩

So (A_{env} (h_1) ∧ (A_{env} (h_1) →A_{env} (h_2)))A_{env} (h_2) is an HFTSs.

2. **Case(i)**

If ⟨h_1^-, 1-h_1^+⟩<⟨h_2^-, 1-h_2^+⟩

A_{env} (h_1)→(((A_{env} (h_1)) ←A_{env} (h_2)) ∨A_{env} (h_2))

=A_{env} (h_1)→(A_{env} (h_1)∨A_{env} (h_2))

=A_{env} (h_1))→A_{env} (h_2)= ⟨1, 0⟩

Case(ii)

If ⟨h_1^-, 1-h_1^+⟩≤⟨h_2^-, 1-h_2^+⟩

A_{env} (h_1))→(⟨1, 0⟩∨A_{env} (h_2))

$A_{env}(h_1))\rightarrow(\langle 1, 0\rangle = \langle h_1^-, 1\text{-}h_1^+\rangle\rightarrow\langle 1, 0\rangle = \langle 1, 0\rangle$

So $A_{env}(h_1)\rightarrow(((A_{env}(h_1))\leftarrow A_{env}(h_2))\vee A_{env}(h_2))$ is an HFTSs.

3. **Case (i)**

If $\langle h_1^-, 1\text{-}h_1^+\rangle\leq\langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1)\rightarrow A_{env}(h_2) = \langle 1, 0\rangle$

$(A_{env}(h_1)\rightarrow A_{env}(h_2))\vee A_{env}(h_1) = (\langle 1, 0\rangle\vee\langle h_1^-, 1\text{-}h_1^+\rangle) = \langle 1, 0\rangle$

$A_{env}(h_2)\rightarrow((A_{env}(h_1)\rightarrow A_{env}(h_2))\vee A_{env}(h_1)) = \langle h_2^-, 1\text{-}h_2^+\rangle\rightarrow\langle 1, 0\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_1^+\rangle>\langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1)\rightarrow A_{env}(h_2) = \langle h_2^-, 1\text{-}h_2^+\rangle$

$((A_{env}(h_1)\rightarrow A_{env}(h_2))\vee A_{env}(h_1)) = (\langle h_2^-, 1\text{-}h_2^+\rangle\vee\langle h_1^-, 1\text{-}h_2^+\rangle)$

$=\langle h_1^-, 1\text{-}h_1^+\rangle$

$A_{env}(h_2)\rightarrow\langle h_1^-, 1\text{-}h_1^+\rangle = \langle h_2^-, 1\text{-}h_2^+\rangle\rightarrow\langle h_1^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

So $A_{env}(h_2)\rightarrow((A_{env}(h_1)\rightarrow A_{env}(h_2))\vee A_{env}(h_1))$ is an HFTSs.

4. **Case (i)**

If $\langle h_1^-, 1\text{-}h_1^+\rangle\geq\langle h_2^-, 1\text{-}h_2^+\rangle$

$(A_{env}(h_1)\vee A_{env}(h_2)) = \langle h_1^-, 1\text{-}h_1^+\rangle$

$(A_{env}(h_1)\vee A_{env}(h_2))\rightarrow A_{env}(h_2) = \langle h_1^-, 1\text{-}h_1^+\rangle\rightarrow\langle h_2^-, 1\text{-}h_2^+\rangle$

$= \langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_2)\rightarrow((A_{env}(h_1)\vee A_{env}(h_2))\rightarrow A_{env}(h_2)) = A_{env}(h_2)\rightarrow\langle h_2^-, 1\text{-}h_2^+\rangle$

$\langle h_2^-, 1\text{-}h_2^+\rangle\rightarrow\langle h_2^-, 1\text{-}h_2^+\rangle = \langle 1, 0\rangle$

Case (ii)

If $\langle h_1^-, 1\text{-}h_2^+\rangle<\langle h_2^-, 1\text{-}h_2^+\rangle$

$A_{env}(h_1)\vee A_{env}(h_2) = \langle h_2^-, 1\text{-}h_2^+\rangle$

$((A_{env}(h_1)\vee A_{env}(h_2))\rightarrow A_{env}(h_2)) = (\langle h_2^-, 1\text{-}h_2^+\rangle\rightarrow\langle h_2^-, 1\text{-}h_2^+\rangle) = \langle 1, 0\rangle$

$A_{env}(h_2)\rightarrow((A_{env}(h_1)\vee A_{env}(h_2))\rightarrow A_{env}(h_2) = A_{env}(h_2)\rightarrow\langle 1, 0\rangle$

$= \langle h_2^-, 1\text{-}h_2^+\rangle\rightarrow\langle 1, 0\rangle = \langle 1, 0\rangle$

So, $A_{env}(h_2)\rightarrow((A_{env}(h_1)\vee A_{env}(h_2))\rightarrow A_{env}(h_2)$ is an HFTSs.

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