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MODIFIED NEW OPERATIONS FOR INTERVAL VALUED INTUITIONISTIC FUZZY NUMBERS (IVIFNS): LINEAR PROGRAMMING PROBLEM WITH HEXAGONAL INTUITIONISTIC FUZZY NUMBERS

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Abstract: This paper addresses the modified arithmetic operations on interval valued intuitionistic fuzzy numbers (IVIFNS) for solving interval valued intuitionistic fuzzy linear programming problem (IVIFLPP) with hexagonal intuitionistic fuzzy numbers by assuming different α and β cut values. An illustrative numerical example is presented in order to clarify the proposed approach and the intuitionistic fuzzy output obtained by MATLAB software is also given.

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Key Words: hexagonal intuitionistic fuzzy number (HIFN), interval valued intuitionistic fuzzy number (IVIFN), interval valued intuitionistic fuzzy arithmetic, intuitionistic fuzzy linear programming problem (IFLPP), interval valued intuitionistic fuzzy linear programming problem (IVIFLPP)

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1. Introduction

The notion of fuzzy sets was introduced by Zadeh [8] and it was generalised to intuitionistic fuzzy sets by Atanassov [1, 2]. The Intuitionistic fuzzy set(IFS) has received more and more attention since its appearance, because the information about attribute values is usually uncertain or fuzzy due to the increasing complexity of the socio-economic environment and the vagueness of inherent subjective nature of human thinking. Therefore, it is desirable to consider the knowledge of experts about the parameters as intuitionistic fuzzy data. These intuitionistic fuzzy parameters are characterized by different intuitionistic fuzzy numbers as triangular, trapezoidal, etc.,

This paper focuses on hexagonal intuitionistic fuzzy numbers (HIFNS) and interval valued intuitionistic fuzzy numbers by assuming various α and β cut values from them. When we consider the interval valued intuitionistic fuzzy numbers(IVIFNS), the arithmetic operations defined on them are of great influence. In the literature, Interval Arithmetic was first suggested by Dwyer [4] in 1951. The same was developed by Moore [6], Ganesan.K. and Veeramani.P[5] and Nagoor Gani. A and Irene Hepzibah. R[7]. Here in this work, we modified the same operations to interval valued intuitionistic fuzzy numbers(IVIFNS) to get the preferred conclusion. Many researchers have applied the intuitionistic fuzzy set theory to the field of decision making. Bellman and Zadeh [3] proposed the concept of decision making In fuzzy envoironment. Zimmermann[9] proposed the first formation of fuzzy linear programming problem.

The paper is organized as follows: Section 2 introduces the preliminaries of hexagonal intuitionistic fuzzy numbers (HIFNS), interval valued intuitionistic fuzzy numbers and the modified arithmetical operations for interval valued intuitionistic fuzzy numbers (IVIFNS). Section 3 deals with the formulation of intuitionistic fuzzy linear programming problem(IFLPP) , interval valued IFLPP and ranking function. Section 4 discusses the algorithm for solving IVIFLPP. In section 5, an application of these new operations is discussed by a numerical illustration and some concluding remarks are given in Section 6.

2. Preliminaries

Definition 1. [1] Given a fixed set $X = \{x_1, x_2, \ldots, x_n\}$, an intuitionistic fuzzy set (IFS) is defined as $\tilde{A}^I = (\langle x_i, \mu_{\tilde{A}^I}(x_i), \nu_{\tilde{A}^I}(x_i)\rangle | x_i \in X)$ which assigns to each element x_i, a membership degree $\mu_{\tilde{A}^I}(x_i)$ and a non-membership degree $\nu_{\tilde{A}^I}(x_i)$ under the condition $0 \leq \mu_{\tilde{A}^I}(x_i) + \nu_{\tilde{A}^I}(x_i) \leq 1$, for all $x_i \in X$.

Definition 2. [1] Let $D(0,1)$ be the set of all closed subintervals of the interval $(0,1)$ and $X(=\phi)$ be a given set. An IVIFS A in X is defined as $\tilde{A}^I = (\langle x_i, \mu_{\tilde{A}^I}(x_i), \nu_{\tilde{A}^I}(x_i)\rangle | x_i \in X)$, where $\mu_{\tilde{A}^I} : X \to D(0,1)$, $\nu_{\tilde{A}^I} : X \to D(0,1)$ with the condition $0 \leq \sup(\mu_{\tilde{A}^I}(x_i)) + \sup(\nu_{\tilde{A}^I}(x_i)) \leq 1$ for any $x \in X$.

Definition 3. A hexagonal intuitionistic fuzzy number (HIFN) $\tilde{A}^I$ is an intuitionistic fuzzy set in R with the following membership function $\mu_{\tilde{A}^I}(x)$ and non-membership function $\nu_{\tilde{A}^I}(x)$

$$\mu_{\tilde{A}^I}(x) = \begin{cases} 0 & , x < a, \\ \dfrac{x-a}{2b-2a}, & a \leq x \leq b, \\ \dfrac{1}{2} + \left(\dfrac{x-b}{2c-2b}\right), & b \leq x \leq c, \\ 1, & c \leq x \leq d, \\ 1 - \left(\dfrac{x-d}{2e-2d}\right), & d \leq x \leq e, \\ \dfrac{f-x}{2f-2e}, & e \leq x \leq f, \\ 0, & x > f, \end{cases}$$

and

$$\nu_{\tilde{A}^I}(x) = \begin{cases} 1, & x < a, \\ \dfrac{2b-a-x}{2b-2a}, & a \leq x \leq b, \\ \dfrac{1}{2} - \left(\dfrac{x-b}{2c-2b}\right), & b \leq x \leq c, \\ 0, & c \leq x \leq d, \\ \dfrac{x-d}{2e-2d}, & d \leq x \leq e, \\ \dfrac{x-2e+f}{2f-2e}, & e \leq x \leq f, \\ 1, & x > f, \end{cases}$$

where $a \leq b \leq c \leq d \leq e \leq f$ and $\mu_{\tilde{A}^I}(x) + \nu_{\tilde{A}^I}(x) \leq 1$ or $\mu_{\tilde{A}^I}(x) = \nu_{\tilde{A}^I}(x)$, for all $x \in R$. This HIFN is denoted by $\tilde{A}^I = \{(a,b,c,d,e,f), \mu_{\tilde{A}^I}(x), \nu_{\tilde{A}^I}(x)\}$. Throughout this paper, HIFN is denoted by $\tilde{A}^I = \{(a,b,c,d,e,f), 1, 0\}$.

Definition 4. A (α,β)- cut set of a intuitionistic fuzzy number is defined as $\tilde{A}^I_{\alpha,\beta} = \{(x|\mu_{\tilde{A}^I}(x) \geq \alpha, \nu_{\tilde{A}^I}(x) \leq \beta\}$, where $0 \leq \alpha \leq 1; 0 \leq \beta \leq 1$ and $0 \leq \alpha + \beta \leq 1$.

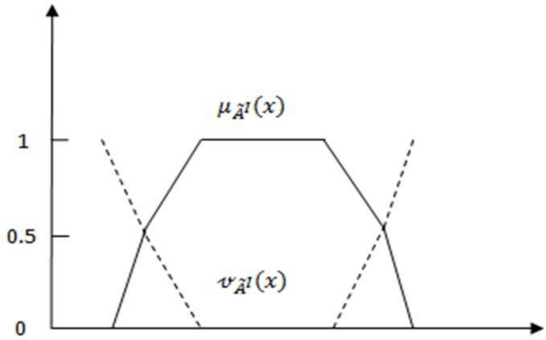

Figure 1: Hexagonal intuitionistic fuzzy number (HIFN)

Definition 5. If $\tilde{A}^I = \{(a,b,c,d,e,f), \mu_{\tilde{A}^I}(x), \nu_{\tilde{A}^I}(x)\}$ is a hexagonal intuitionistic fuzzy number, we will let $\tilde{A}^I_{(\alpha,\beta)} = \{(A^-_\alpha, A^+_\alpha); (A^-_\beta, A^+_\beta)\}$ where $(A^-_\alpha, A^+_\alpha) = (a+2\alpha(b-a), f-2\alpha(f-e))$ be the closed interval which is a α-cut for $\tilde{A}^I$ in $0 \le \alpha \le \frac{1}{2}$ and where $(A^-_\beta, A^+_\beta) = ((2b-a)-2\beta(b-a), (2e-f)+2\beta(f-e)$ be the closed interval which is a β-cut for $\tilde{A}^I$ in $\frac{1}{2} \le \beta \le 1$ and also we will let $\tilde{A}^I_{(\alpha,\beta)} = \{(A^-_\alpha, A^+_\alpha); (A^-_\beta, A^+_\beta)\}$ where $(A^-_\alpha, A^+_\alpha) = ((2b-c)+2\alpha(c-b), (2e-d)-2\alpha(e-d))$ be the closed interval which is a α-cut for $\tilde{A}^I$ in $\frac{1}{2} \le \alpha \le 1$ and where $(A^-_\beta, A^+_\beta) = (c-2\beta(c-b), d+2\beta(e-d))$ be the closed interval which is a β-cut for $\tilde{A}^I$ in $0 \le \beta \le \frac{1}{2}$.

Definition 6. A positive interval valued intuitionistic fuzzy number is denoted as $\{(a_1, a_2); (a_1', a_2')\}$ where all a_is and a_i's > 0 for all $i = 1, 2$.

Definition 7. A negative interval valued intuitionistic fuzzy number is denoted as $\{(a_1, a_2); (a_1', a_2')\}$ where all a_is and a_i's < 0 for all $i = 1, 2$.

Definition 8 (Modified operations of interval valued intuitionistic fuzzy numbers using function principle)**.** According to K.Ganesan and P.Veeramani [5], the following are the modified operations that can be performed on interval valued intuitionistic fuzzy numbers:

Let $\tilde{A}^I = \{(a_1, a_2); (a_1', a_2')\}$ and $\tilde{B}^I = \{(b_1, b_2); (b_1', b_2')\}$. Then we define $m_1 = \dfrac{a_1 + a_2}{2}$, $m_2 = \dfrac{a_1 + a_2}{2}$, $m_1' = \dfrac{a_1', +a_2'}{2}$ and $m_2' = \dfrac{b_1' + b_2'}{2}$.

(i) **Addition:**

$$\tilde{A}^I + \tilde{B}^I = \{((m_1+m_2-k); (m_1+m_2+k)); ((m_1'+m_2'-k'), (m_1', +m_2'+k'))\},$$

where $k = \dfrac{(b_2 + a_2) - (b_1 + a_1)}{2}, k^{'} = \dfrac{(b_2{}' + a_2^{'}) - (b_1^{'} + a_1^{'})}{2}$.

(ii) **Subtraction:**

$$\tilde{A}^I - \tilde{B}^I = \{((m_1 - m_2 - k); (m_1 - m_2 + k)); ((m_1^{'} - m_2^{'} - k'), (m_1^{'} - m_2^{'} + k^{'}))\},$$

where $k = \dfrac{(b_2 + a_2) - (b_1 + a_1)}{2}, k^{'} = \dfrac{(b_2{}' + a_2^{'}) - (b_1^{'} + a_1^{'})}{2}$.

(iii) **Multiplication:**

$$\tilde{A}^I X \tilde{B}^I = \{((m_1 m_2 - k); (m_1 m_2 + k)); ((m_1^{'} m_2^{'} - k^{'}), (m_1^{'} m_2^{'} + k^{'}))\},$$

where $k = \min\{(m_1 m_2 - \alpha, \beta - m_1 m_2)\}$,
$\alpha = \min(a_1 b_1, a_1 b_2, a_2 b_1, a_2 b_2)$, $\beta = \max(a_1 b_1, a_1 b_2, a_2 b_1, a_2 b_2)$,
$k^{'} = \min\{(m_1^{'} m_2^{'} - \alpha, \beta - m_1^{'} m_2^{'})\}$, $\alpha^{'} = \min(a_1^{'} b_1^{'}, a_1^{'} b_2{}', a_2^{'} b_1^{'}, a_2^{'} b_2^{'})$,
$\beta^{'} = \max(a_1^{'} b_1^{'}, a_1^{'} b_2^{'}, a_2^{'} b_1^{'}, a_2^{'} b_2{}')$.

(iv) **Inverse:**

$$\frac{1}{\tilde{A}^I} = \{(a_1, a_2); (a_1^{'}, a_2^{'})\}^{-1} = \Big[(\frac{1}{m_1} - k, \frac{1}{m_1} + k); (\frac{1}{m_1^{'}} - k^{'}, \frac{1}{m_1^{'}} + k^{'})\Big],$$

where $k = \min\left\{\dfrac{1}{a_2}\left(\dfrac{a_2 - a_1}{a_1 + a_2}\right), \dfrac{1}{a_1}\left(\dfrac{a_2 - a_1}{a_1 + a_2}\right)\right\}$,
$k^{'} = \min\left\{\dfrac{1}{a_2^{'}}\left(\dfrac{a_2^{'} - a_1^{'}}{a_1^{'} + a_2^{'}}\right), \dfrac{1}{a_1^{'}}\left(\dfrac{a_2^{'} - a_1^{'}}{a_1^{'} + a_2^{'}}\right)\right\}$.
for all positive real numbers $a_1, a_2, a_1^{'}, a_2^{'}$ and $0 \notin \{(a_1, a_2); (a_1^{'}, a_2^{'})\}$.
If $a_1, a_1^{'} < 0$, $a_1 = a_1^{'}, |a_1| < |a_2|$ and $|a_1^{'}| < |a_2^{'}|$ the above operation is not working. So in that case, the quantities k and k' are proposed as

$$k = \min\left\{\frac{1}{|a_2|}\left(\frac{|a_2| - |a_1|}{|a_1| + |a_2|}\right), \frac{1}{|a_1|}\left(\frac{|a_2| - |a_1|}{|a_1| + |a_2|}\right)\right\},$$

$$k^{'} = \min\left\{\frac{1}{|a_2^{'}|}\left(\frac{|a_2^{'}| - |a_1^{'}|}{|a_1^{'}| + |a_2^{'}|}\right), \frac{1}{|a_1^{'}|}\left(\frac{|a_2^{'}| - |a_1^{'}|}{|a_1^{'}| + |a_2^{'}|}\right)\right\}.$$

(v) **Scalar multiplication:** Let $\lambda \in R$. Then

$$\lambda \tilde{A}^I = \begin{cases} \{(\lambda a_1, \lambda a_2); (\lambda a_1^{'}, \lambda a_2^{'})\}, & \text{for } \lambda \geq 0, \\ \{(\lambda a_2, \lambda a_1); (\lambda a_2^{'}, \lambda a_1^{'})\}, & \text{for } \lambda < 0. \end{cases}$$

3. Formulation of Problem

3.1. Formulation of the Intuitionistic Fuzzy Linear Programming Problem (IFLPP)

The general form of optimization problem with intuitionistic fuzzy objective function $\tilde{z}^I$ and m intuitionistic fuzzy constraints is given by

$$\left.\begin{aligned} \text{Maximize or Maximize } \tilde{z}^I &= \sum_{j=1}^{n} (\tilde{c}_j^I)\,(\tilde{x}_j^I), \\ \text{subject to } & \sum_{j=1}^{n} \tilde{a}_{ij}^I \tilde{x}_j^I \leq \tilde{b}_i^I, \tilde{x}_j^I \geq 0, \end{aligned}\right\} \quad \text{(a)}$$

where $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$ where $\tilde{A}^I = (\tilde{a}_{ij}^I), \tilde{C}_j^I, \tilde{b}^I$, are hexagonal intuitionistic fuzzy numbers (HIFNS) and $\tilde{x}_j^I$ whose states are also given by hexagonal intuitionistic fuzzy numbers (HIFNS).

3.2. Formulation of the Interval Valued Intuitionistic Fuzzy Linear Programming Problem (IVIFLPP)

By assuming prescribed values of α and β, the above problem (a) can be restated as

$$\left.\begin{aligned} \text{Maximize or Minimize } &: (\tilde{z}^I)_{(\alpha,\beta)} = \sum_{j=1}^{n} (\tilde{c}_i^I)_{(\alpha,\beta)} (\tilde{x}_j^I)_{(\alpha,\beta)}, \\ \text{Subject to } & \sum_{j=1}^{n} (\tilde{a}_{ij}^I)_{(\alpha,\beta)} (\tilde{x}_i^I)_{(\alpha,\beta)} \leq (\tilde{b}_i^I)_{(\alpha,\beta)}, \\ & (\tilde{x}_i^I)_{(\alpha,\beta)} \geq 0, \end{aligned}\right\} \quad \text{(b)}$$

where $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$ where $(\tilde{a}_{ij}^I)_{(\alpha,\beta)} (\tilde{c}_j^I)_{(\alpha,\beta)}, (\tilde{b}_i^I)_{(\alpha,\beta)}$, are interval valued intuitionistic fuzzy numbers (IVIFNS) and $(\tilde{x}_j^I)_{(\alpha,\beta)}$ whose states are also given by interval valued intuitionistic fuzzy numbers (IVIFNS).

3.3. Ranking Function

Let $\Re : F(\tilde{A}^I) \to \mathbb{R}$ be a linear ordered function that maps each interval valued intuitionistic fuzzy number into the real number, given by $\Re(\tilde{A}^I) = \frac{1}{4}(a + b + c + d)$, where $\tilde{A}^I = \{(a, b); (c, d)\}$, in which $F(\tilde{A}^I)$ denotes the whole interval valued intuitionistic fuzzy numbers. Accordingly, for any two IVIFNS we have $\tilde{A}^I \succeq \tilde{B}^I$ iff $\Re(\tilde{A}^I) \succeq \Re(\tilde{B}^I)$; $\tilde{A}^I \preceq \tilde{B}^I$ iff $\Re(\tilde{A}^I) \preceq \Re(\tilde{B}^I)$ and $\tilde{A}^I = \tilde{B}^I$ iff $\Re(\tilde{A}^I) = \Re(\tilde{B}^I)$.

4. Algorithm for Solving Linear Programming Problem with Intuitionistic Fuzzy Numbers

As per the above details, the proposed algorithm for solving linear programming problem with intuitionistic fuzzy numbers is given below.

Step 1. Consider the IFLPP Maximize or Minimize $\tilde{Z}^I = \sum_{j=1}^{n} \tilde{c}_j^I \tilde{x}_j^I$, Subject to the constraints $\sum_{j=1}^{n} \tilde{a}_{ij}^I \tilde{x}_j^I \leq$ or $\geq \tilde{b}_i^I, \tilde{x}_j^I \geq 0$.

Step 2. Set α and β cut level values, to formulate the above problem into interval valued intuitionistic fuzzy linear programming problem(IVIFLPP).

Step 3. Compute the net evaluations $\tilde{z}_j^I - \tilde{c}_j^I$ $(j = 1, 2, 3, \ldots, n)$ by using the relation $\tilde{z}_j^I - \tilde{c}_j^I = \tilde{c}_B^I \tilde{a}_j^I - \tilde{c}_j^I$. Examine the sign of $\tilde{z}_j^I - \tilde{c}_j^I$.

(i) If all $\tilde{z}_j^I - \tilde{c}_j^I \geq 0$ by 3.3, then the current basic feasible solution $\tilde{X}_B^I$ is optimal.

(ii) If atleast one $\tilde{z}_j^I - \tilde{c}_j^I < 0$ by 3.3, then the current basic feasible solution is not optimal, go to the next step.

Step 4. The entering variable is the non-basic variable corresponding to the most negative value of $\tilde{z}_j^I - \tilde{c}_j^I$. Let it be $\tilde{x}_r^I$ for some $j = r$.

Step 5. Compute the ratio $R = \min\left\{\dfrac{\tilde{X}_{B_i}^I}{\tilde{a}_{ir}}, \tilde{a}_{ir} > 0\right\}$, If $R = \dfrac{\tilde{X}_{B_k}^I}{\tilde{a}_{kr}}$ then the basic variable leaves the basis.

Step 6. Drop the leaving variable and introduce the entering variable along with associated value under $\tilde{c}_B^I$ column. Convert the pivot element to unity $(\tilde{1}^I)$ which is verified by 3.3.

Step 7. Go to Step 2 and repeat the procedure until either an optimum solution is obtained.

5. Illustrative Example

Consider the following IFLPP:

$$\text{Maximize } \tilde{z}^I = \{(-3.5, -0.5, 2.5, 5.5, 8.5, 11.5); 1, 0\}\tilde{x}_1^I + \{(3, 6, 9, 11, 14, 17); 1, 0\}\tilde{x}_2^I,$$

Subject to the constraints:

$$\left.\begin{array}{l} \{(-5, -2, 1, 3, 6, 9); 1, 0\}\tilde{x}_1^I \\ \quad +\{(-7.5, -4.5, -1.5, 3.5, 6.5, 9.5); 1, 0\}\tilde{x}_2^I \\ \leq \{(-2, 1, 4, 6, 9, 12); 1, 0\}, \\ \{(-5, -2, 1, 3, 6, 9); 1, 0\}\tilde{x}_1^I + \{(-2, 1, 4, 6, 9, 12); 1, 0\}\tilde{x}_2^I \\ \leq \{(3, 6, 9, 11, 14, 17); 1, 0\}, \tilde{x}_1^I, \tilde{x}_2^I \geq 0. \end{array}\right\} \quad (c)$$

Solving the above IFLPP, we first reduce it into the following IVIFLPP by taking different α and β -cuts.

When $\alpha = 0$, β=1, Model (c) takes the form,

$$\text{Maximize } \quad \tilde{z}^I \quad = \quad \{(-3.5, 11.5); (-3.5, 11.5)\}\tilde{x}_1^I \ + \ \{(3, 17); (3, 17)\}\tilde{x}_2^I,$$

subject to the constraints

$$\begin{aligned} &\{(-5, 9); (-5, 9)\}\tilde{x}_1^I + \{(-7.5, 9.5); (-7.5, 9.5)\}\tilde{x}_2^I \\ &\qquad \leq \{(-2, 12); (-2, 12)\} \\ &\{(-5, 9); (-5, 9)\}\tilde{x}_1^I + \{(-2, 12); (-2, 12)\}\tilde{x}_2^I \leq \{(3, 17); (3, 17)\} \\ &\qquad \tilde{x}_1^I, \tilde{x}_2^I \geq 0. \end{aligned}$$

By simplex algorithm, We observed that all $\tilde{z}_j^I - \tilde{c}_j^I \geq 0$ (by 3.3). Then the current solution is optimal (by 3.3) and the optimal solution is as

$$\tilde{x}_1^I = \{(0, 0); (0, 0)\}, \quad \tilde{x}2^I = \{(0.42, 3.58); (0.42, 3.58)\}$$

with Maximize

$$\tilde{Z}^I = \{(1.26, 38.74); (1.26, 38.74)\}.$$

The optimal solution of the IFLPP for using different α, β cut values, the optimum values of $\tilde{z}^I$ and also the MATLAB output are also given below:

The MATLAB output of the above example is shown below:

α-values	β- values	Optimum $\tilde{Z}^I$-values
α =0	β =1	$\tilde{Z}^I$ ={ (1.26,38.74);(1.26,38.74)}
α =0.1	β =0.9	$\tilde{Z}^I$ ={ (1.79,38.81);(1.79,38.81)}
α =0.2	β =0.8	$\tilde{Z}^I$ ={ (2.1,37.9);(2.1,37.9)}
α =0.3	β =0.7	$\tilde{Z}^I$ ={ (2.54,37.46);(2.54,37.46)}
α =0.4	β =0.6	$\tilde{Z}^I$ ={ (2.92,37.08);(2.92,37.08)}
α =0.5	β =0.5	$\tilde{Z}^I$ ={ (3.96,36.04);(3.96,36.04)}
α =0.6	β =0.4	$\tilde{Z}^I$ ={ (5.21,34.79);(5.21,34.79)}
α =0.7	β =0.3	$\tilde{Z}^I$ ={ (6.67,33.23);(6.67,33.23)}
α =0.8	β =0.2	$\tilde{Z}^I$ ={ (8.50,31.5);(8.50,31.5)}
α =0.9	β =0.1	$\tilde{Z}^I$ ={ (10.58,29.42);(10.58,29.42)}
α =1	β =0	$\tilde{Z}^I$ ={ (13.77,26.23);(13.77,26.23)}

Table 1: The optimum values for prescribed values of α and β

6. Conclusion

This paper reveals how the modified operations can be efficiently used for linear programming problem with hexagonal intuitionistic fuzzy numbers. For prescribed values of α and β, the IFLPP is reduced to a deterministic IVIFLPP and the optimum values are tabulated. Finally, the diagrammatic output by MATLAB software is given. Although here we are considering the linear case, we can extend these operations into non-linear programming with interval valued intuitionistic fuzzy coefficients.

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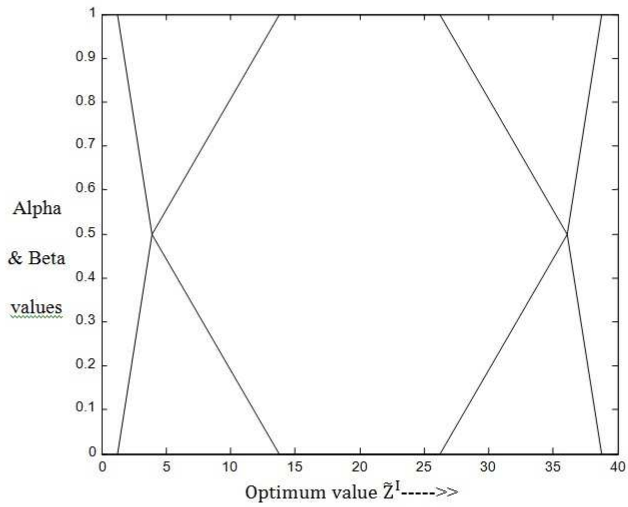

Figure 2: Hexagonal Intuitionistic Fuzzy Output

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