Transportation Problem with Heptagonal Intuitionistic Fuzzy Number Solved Using Value Index and Ambiguity Index

Dr.V.Kamal Nasir [1], V.P.Beenu [2]

[1] Associate Professor
Department of Mathematics
The New College
Royapettah, Chennai-14
kamalnasar2000@gmail.com
[2]Research Scholar, The New College
University of Madras, Chennai-05
[2] Assistant Professor
Department of Mathematics
Justice Basheer Ahmed Sayeed College For Women
Teynampet, Chennai-18
beenu.vinod1982@gmail.com

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Abstract
This paper proposes a new ranking technique to solve transportation problems in an intuitionistic fuzzy environment. Heptagonal Intuitionistic Fuzzy Number with degree of membership and degree of non-membership function represent the demand and supply of the transportation problems and cost of the transportation problem as real values. The validity of the proposed method is illustrated with an example involving a transportation problem for miminizing cost with Heptagonal intuitionistic fuzzy number. The proposed ranking method is used to convert Heptagonal Intuitionistic Fuzzy Number into crisp values to solve the transportation problem.
Keywords: Intuitionistic Fuzzy Number, Heptagonal Intuitionistic Fuzzy Number (HpIFN), value index, ambiguity index, alpha cut and beta cut.

1. INTRODUCTION: Fuzzy set theory was introduced by Zadeh [10] in the year 1965. The concept on Intuitionistic Fuzzy Number was introduced by Atanassov[3]. An Intuitionistic Fuzzy set is a powerful tool which deals with vagueness. There are many models in transportation problem which play an important role in reducing cost, maximizing profit and improving service. Intuitionistic Fuzzy Numbers are used in many applications of decision theory for research. In this paper an illustrative example for minimizing cost with Heptagonal intuitionistic fuzzy demand and supply along with degree of acceptance and degree of rejection is solved. The initial basic feasible solution is obtained by Intuitionistic fuzzy Vogel's Approximation method and optimal solution by fuzzy modified distribution method. The Heptagonal intutionistic fuzzy numbers are converted to crisp values by using value and ambiguity index based ranking method.

2. PRELIMINARIES

Definition 2.1[2]: **Intuitionistic fuzzy set:** Let X be a universal set. An Intuitionistic fuzzy set A^I in X is A^I= {x,μ_{A^I}(x), ϑ_{A^I}(x)):x∈X} where the function μ_{A^I} : x→[0,1] , ϑ_{A^I} : x→[0,1]

define the degree of membership and the degree of non-membership of the element x∈X to the set A^I respectively and for every x∈X in A^I ,$0 \leq \mu_{A^I}$ (x)+ ϑ_{A^I} (x) ≤ 1 holds .

3. Heptagonal intuitionistic fuzzy numbers

Definition 3.1: Heptagonal intuitionistic fuzzy number:

A HpIFN $\tilde{a}^I = < (a_1, a_2, a_3, a_4, a_5, a_6, a_7)(b_1, b_2, b_3, b_4, b_5, b_6, b_7); w_{\tilde{a}}, u_{\tilde{a}} >$ is a Intuitionistic Fuzzy

set on a set of real number R, whose membership and non-membership functions are defined as:

MEMBERSHIP FUNCTION

$$\mu_{\tilde{a}^I}(x) = \begin{cases} \frac{w_1(x-a_1)}{(a_2-a_1)} & , a_1 \leq x \leq a_2 \\ w_1 & , a_2 \leq x \leq a_3 \\ w_1 + \frac{(w_{\tilde{a}}-w_1)(x-a_3)}{(a_4-a_3)} & , a_3 \leq x \leq a_4 \\ w_{\tilde{a}} & , x = a_4 \\ w_1 + \frac{(w_{\tilde{a}}-w_1)(a_5-x)}{(a_5-a_4)} & , a_4 \leq x \leq a_5 \\ w_1 & , a_5 \leq x \leq a_6 \\ \frac{w_1\,(a_7-x)}{(a_7-a_6)} & , a_6 \leq x \leq a_7 \\ 0 & , otherwise \end{cases}$$

NON-MEMBERSHIP FUNCTION

$$\vartheta_{\tilde{a}^I}(x) = \begin{cases} w_1 + \frac{(1-w_1)(b_2-x)}{(b_2-b_1)} & , b_1 \leq x \leq b_2 \\ w_1 & , b_2 \leq x \leq b_3 \\ u_{\tilde{a}} + \frac{(w_1-u_{\tilde{a}})(b_4-x)}{(b_4-b_3)} & , b_3 \leq x \leq b_4 \\ u_{\tilde{a}} & , x = b_4 \\ u_{\tilde{a}} + \frac{(w_1-u_{\tilde{a}})(x-b_4)}{(b_5-b_4)} & , b_4 \leq x \leq b_5 \\ w_1 & , b_5 \leq x \leq b_6 \\ w_1 + \frac{(1-w_1)(x-b_6)}{(b_7-b_6)} & , b_6 \leq x \leq b_7 \\ 1 & , otherwise \end{cases}$$

The value $w_{\tilde{a}}$ represent the maximum degree of membership and the value $u_{\tilde{a}}$ minimum degree of non-membership such that $0 \leq w_{\tilde{a}}$ (x) ≤ 1 , $0 \leq u_{\tilde{a}}$ (x) ≤ 1, $0 \leq w_{\tilde{a}} + u_{\tilde{a}}$ (x) ≤ 1 are satisfied.

4. Arithmetical Operations

Let $\tilde{a}^I = < (a_1, a_2, a_3, a_4, a_5, a_6, a_7)\ (c_1, c_2, c_3, c_4, c_5, c_6, c_7); w_{\tilde{a}}, u_{\tilde{a}} >$ and

$\tilde{b}^I = < (b_1, b_2, b_3, b_4, b_5, b_6, b_7)\ (d_1, d_2, d_3, d_4, d_5, d_6, d_7); w_{\tilde{b}}, u_{\tilde{b}} >$ be two HpIFNs and λ be a real number. Then the arithmetical operations are

$\tilde{a}^I+\tilde{b}^I$ = < $(a_1+b_1, a_2+b_2, a_3+b_3, a_4+b_4, a_5+b_5, a_6+b_6, a_7+b_7; c_1+d_1, c_2+d_2, c_3+d_3, c_4+d_4, c_5+d_5, c_6+d_6, c_7+d_7)$; min$\{w_{\tilde{a}}, w_{\tilde{b}}\}$, max$\{u_{\tilde{a}}, u_{\tilde{b}}\}$ >

$\tilde{a}^I - \tilde{b}^I$ = < $a_1-b_7, a_2-b_6, a_3-b_5, a_4-b_4, a_5-b_3, a_6-b_2, a_7-b_1; c_1-d_7, c_2-d_6, c_3-d_5, c_4-d_4, c_5-d_3, c_6-d_2, c_7-d_1)$; min $\{w_{\tilde{a}}, w_{\tilde{b}}\}$, max$\{u_{\tilde{a}}, u_{\tilde{b}}\}$ >

$\tilde{a}^I * \tilde{b}^I$= < $(a_1b_1, a_2b_2, a_3b_3, a_4b_4, a_5b_5, a_6b_6, a_7b_7; c_1d_1, c_2d_2, c_3d_3, c_4d_4, c_5d_5, c_6d_6, c_7d_7)$; min$\{w_{\tilde{a}}, w_{\tilde{b}}\}$, max$\{u_{\tilde{a}}, u_{\tilde{b}}\}$ > Where $\tilde{a}$ and $\tilde{b}$ are non-negative heptagonal intuitionistic fuzzy numbers

$\lambda\, \tilde{a}^I$ = < $(\lambda a_1, \lambda a_2, \lambda a_3, \lambda a_4, \lambda a_5, \lambda a_6, \lambda a_7; \lambda c_1, \lambda c_2, \lambda c_3, \lambda c_4, \lambda c_5, \lambda c_6, \lambda c_7);\ w_{\tilde{a}}, u_{\tilde{a}}$ > ; $\lambda \geq 0$,

< $(\lambda a_1, \lambda a_2, \lambda a_3, \lambda a_4, \lambda a_5, \lambda a_6, \lambda a_7; \lambda c_1, \lambda c_2, \lambda c_3, \lambda c_4, \lambda c_5, \lambda c_6, \lambda c_7);\ w_{\tilde{a}}, u_{\tilde{a}}$ > ; $\lambda < 0$

$\tilde{a}^{I^{-1}}$ = < $(\frac{1}{a_7}, \frac{1}{a_6}, \frac{1}{a_5}, \frac{1}{a_4}, \frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}; \frac{1}{c_7}, \frac{1}{c_6}, \frac{1}{c_5}, \frac{1}{c_4}, \frac{1}{c_3}, \frac{1}{c_2}, \frac{1}{c_1})$; $w_{\tilde{a}}, u_{\tilde{a}}$ >

5. α-cut sets and β-cut sets of Heptagonal Intuitionistic Fuzzy Number (HpIFN):

5.1: A α-cut set of a HpIFN $\tilde{a}^I$ = < $(a_1, a_2, a_3, a_4, a_5, a_6, a_7)(b_1, b_2, b_3, b_4, b_5, b_6, b_7); w_{\tilde{a}}, u_{\tilde{a}}$ > is a

crisp subset of R defined as ${\tilde{a}^I}_\alpha = \{x|\mu_{A^I}(x) \geq \alpha\}$ where $0 \leq \alpha \leq w_{\tilde{a}}$.

5.2: A β-cut set of a HpIFN $\tilde{a}^I$ = < $(a_1, a_2, a_3, a_4, a_5, a_6, a_7)(b_1, b_2, b_3, b_4, b_5, b_6, b_7); w_{\tilde{a}}, u_{\tilde{a}}$ > is a

crisp subset of R defined as ${\tilde{a}^I}_\beta = \{x|\vartheta_{A^I}(x) \leq \beta\}$ where $u_{\tilde{a}} \leq \beta \leq 1$

${\tilde{a}^I}_\alpha$ and ${\tilde{a}^I}_\beta$ are both closed sets and are denoted by ${\tilde{a}^I}_\alpha = [L_{\tilde{a}^I}(\alpha), R_{\tilde{a}^I}(\alpha)]$ and ${\tilde{a}^I}_\beta = [L_{\tilde{a}^I}(\beta), R_{\tilde{a}^I}(\beta)]$ repectively. The respective values of $\tilde{a}_\alpha$ and $\tilde{a}_\beta$ are calculated as follows:

$[a_1 + \frac{\alpha(a_2-a_1)}{w_1}, a_7 - \frac{\alpha(a_7-a_6)}{w_1}]$ where $\alpha \epsilon\ [0, w_1]$

$[\frac{w_{\tilde{a}}a_3+\alpha(a_4-a_3)-w_1a_4}{(w_{\tilde{a}}-w_1)}, \frac{w_{\tilde{a}}a_5-\alpha(a_5-a_4)-w_1a_4}{(w_{\tilde{a}}-w_1)}]$ where $\alpha \epsilon\ (w_1, w_{\tilde{a}}]$

$[\frac{w_1b_4-\beta(b_4-b_3)-u_{\tilde{a}}b_3)}{(w_1-u_{\tilde{a}})}, \frac{w_1b_4+\beta(b_5-b_4)-u_{\tilde{a}}b_5)}{(w_1-u_{\tilde{a}})}]$ where $\beta \epsilon\ [u_{\tilde{a}}, w_1]$

$[\frac{b_2-\beta(b_2-b_1)-w_1b_1}{(1-w_1)}, \frac{b_6+\beta(b_7-b_6)-w_1b_7}{(1-w_1)}]$ where $\beta \epsilon\ (w_1, 1]$

6. Ranking of HpIFNs based on Value and Ambiguity

The value and ambiguity of a HpIFN and NIFN can be defined similar to those of a TIFNs introduced by D.F.Li [5].

Definition 6.1:

Let ${\tilde{a}^I}_\alpha$and ${\tilde{a}^I}_\beta$ be an α-cut set and β-cut set of a Heptagonal Intuitionistic Fuzzy Number

$\tilde{a}^I = < (a_1, a_2, a_3, a_4, a_5, a_6, a_7)(b_1, b_2, b_3, b_4, b_5, b_6, b_7);\ w_{\tilde{a}}, u_{\tilde{a}} >$

Then the values of the membership function $\mu_{\tilde{a}}(x)$ and the values of the non-membership function $\vartheta_{\tilde{a}}$ (x) for the HpIFN $\tilde{a}^I$ is defined as follows

$$V_\mu(\tilde{a}^I) = \int_0^{w_{\tilde{a}}} \frac{L_{\tilde{a}^I}(\alpha) + R_{\tilde{a}^I}(\alpha)}{2} f(\alpha)d\alpha \quad \text{......................................} (1)$$

$$V_\vartheta(\tilde{a}^I) = \int_{u_{\tilde{a}}}^{1} \frac{L_{\tilde{a}^I}(\beta) + R_{\tilde{a}^I}(\beta)}{2} g(\beta)d\beta \quad \text{......................................} (2)$$

Respectively, where the function f(α) is a non-negative and non-decreasing function on the interval $[0, w_{\tilde{a}}]$ with f(0)=0 and $\int_0^{w_{\tilde{a}}} f(\alpha)d\alpha = w_{\tilde{a}}$ The function g(β) is a non-negative and non-increasing function on the interval $[u_{\tilde{a}},1]$ with g(1)=0 and $\int_{u_{\tilde{a}}}^{1} g(\beta)d\beta = 1 - u_{\tilde{a}}$. Throughout the paper we shall choose $f(\alpha) = \frac{2\alpha}{w_{\tilde{a}}}$, $\alpha \in [0, w_{\tilde{a}}]$ and $g(\beta) = \frac{2(1-\beta)}{1-u_{\tilde{a}}}$ where $\beta \in [u_{\tilde{a}},1]$.

The value of the membership function of a HpIFN $\tilde{a}^I$ is calculated as follows:

$$V_\mu(\tilde{a}^I) = \frac{w_1^2(a_1 + 2a_2 + 2a_6 + a_7)}{6w_{\tilde{a}}} + \frac{(w_{\tilde{a}} + w_1)[w_{\tilde{a}}(a_3 + a_5) - 2w_1a_4]}{2w_{\tilde{a}}} + \frac{(w_{\tilde{a}}^2 + w_{\tilde{a}}w_1 + w_1^2)(2a_4 - a_3 - a_5)}{3w_{\tilde{a}}} \text{......................} (3)$$

The value of the non- membership function of a HpIFN $\tilde{a}^I$ is calculated as follows:

$$V_\vartheta(\tilde{a}^I) = \frac{1}{(1-u_{\tilde{a}})(w_1-u_{\tilde{a}})}\left[\frac{(2w_1 - w_1^2 - 2u_{\tilde{a}} + u_{\tilde{a}}^2)(2w_1b_4 - u_{\tilde{a}}(b_3 + b_5))}{2} + \frac{(3w_1^2 - 2w_1^3 - 3u_{\tilde{a}}^2 + 2u_{\tilde{a}}^3)(b_5 - 2b_4 + b_3)}{6}\right] + \left[\frac{(1-w_1)((b_2 + b_6) - w_1(b_1 + b_7))}{2(1-u_{\tilde{a}})}\right] + \left[\frac{(1 - 3w_1^2 + 2w_1^3)(b_7 - b_6 - b_2 + b_1)}{6(1-u_{\tilde{a}})(1-w_1)}\right] \text{......................................} (4)$$

With the condition that $0 \le w_{\tilde{a}} + u_{\tilde{a}} \le 1$,it follows that $V_\mu(\tilde{a}^I) \le V_\vartheta(\tilde{a}^I)$ thus the values of the membership and non-membership function of a HpIFN $\tilde{a}^I$ can be expressed as an interval $[V_\mu(\tilde{a}^I), V_\vartheta(\tilde{a}^I)]$.

Definition 6.2: Let $\tilde{a}^I{}_\alpha$ and $\tilde{a}^I{}_\beta$ be an α-cut set and β-cut set of a

HpIFN $\tilde{a}^I = < (a_1, a_2, a_3, a_4, a_5, a_6, a_7)(b_1, b_2, b_3, b_4, b_5, b_6, b_7);\ w_{\tilde{a}}, u_{\tilde{a}} >$

Then the ambiguities of the membership function $\mu_{\tilde{a}}(x)$ and the ambiguities of the non-membership function $\vartheta_{\tilde{a}}(x)$ for the HpIFN $\tilde{a}^I$ and NIFN $\tilde{a}^I$ are defined as follows

$$A_\mu(\tilde{a}^I) = \int_0^{w_{\tilde{a}}} R_{\tilde{a}^I}(\alpha) - L_{\tilde{a}^I}(\alpha) f(\alpha)d\alpha \quad \text{......................................} (5)$$

$$A_\nu(\tilde{a}^I) = \int_{u_{\tilde{a}}}^{1} R_{\tilde{a}^I}(\beta) - L_{\tilde{a}^I}(\beta) g(\beta)d\beta \quad \text{......................................} (6)$$

It can be followed from definition of $A_\mu(\tilde{a}^I)$ and $A_\vartheta(\tilde{a}^I)$ that $A_\mu(\tilde{a}^I) \ge 0$, $A_\vartheta(\tilde{a}^I) \ge 0$

The ambiguity of the membership function of a HpIFN $\tilde{a}^I$ is evaluated as follows.

$A_{\mu}(\tilde{a}^{I}) = \frac{w_1^2(a_7+2a_6-2a_2-a_1)}{3w_{\tilde{a}}} + \frac{(a_5-a_3)(w_{\tilde{a}}^2+w_{\tilde{a}}w_1-2w_1^2)}{3w_{\tilde{a}}}$ ....(7)

Similarly, the ambiguity of the non-membership function of a HpIFN $\tilde{a}^{I}$ is evaluated as follows.

$A_{\vartheta}(\tilde{a}^{I}) = \frac{(b_5-b_3)[(3w_1^2-2w_1^3-3u_{\tilde{a}}^2+2u_{\tilde{a}}^3)-3u_{\tilde{a}}(2w_1-w_1^2-2u_{\tilde{a}}+u_{\tilde{a}}^2)]}{3(1-u_{\tilde{a}})(w_1-u_{\tilde{a}})} + \frac{(1-w_1)[(b_6-b_2)-w_1(b_7-b_1)]}{(1-u_{\tilde{a}})}$

$+\frac{(1-3w_1^2+2w_1^3)(b_7-b_6+b_2-b_1)}{3(1-u_{\tilde{a}})(1-w_1)}$ .... (8)

With the condition that $0 \leq w_{\tilde{a}} + u_{\tilde{a}} \leq 1$,it follows that $A_{\mu}(\tilde{a}^{I}) \leq A_{\vartheta}(\tilde{a}^{I})$ thus the values of the membership and non-membership function of a HpIFN $\tilde{a}^{I}$ and NIFN $\tilde{a}^{I}$ can be expressed as an interval $[A_{\mu}(\tilde{a}^{I}), A_{\vartheta}(\tilde{a}^{I})]$.

7. The Ranking Technique [9]:

Ranking is evaluated by taking the sum of value index and ambiguity index

$R(\tilde{n}^{I}) = V(\tilde{n}^{I}, \frac{1}{2}) + A(\tilde{n}^{I}, \frac{1}{2})$ .... (9)

Where $V(\tilde{n}^{I}, \frac{1}{2}) = \frac{V_{\mu}(\tilde{n}^{I}) + V_{\vartheta}(\tilde{n}^{I})}{2}$, $A(\tilde{n}^{I}, \frac{1}{2}) = \frac{A_{\mu}(\tilde{n}^{I}) + A_{\vartheta}(\tilde{n}^{I})}{2}$

8. Initial Basic Feasible Solution by Intuitionistic fuzzy Vogel's Approximation method for heptagonal intuitionistic fuzzy balanced transportation problem for profit minimization

1. In Intuitionistic fuzzy transportation problem, the heptagonal intuitionistic fuzzy transportation cost are reduced to crisp numbers using value and ambiguity based ranking.

2. In the reduced HpIFTP, identify the row and column difference considering the least two numbers of the respective row and column.

3. Select the maximum among the difference and allocate the respective demand or supply to the minimum value of the corresponding row or column.

4. We take the difference of the corresponding supply and demand of the allocated cell which leads either of the one to zero, eliminating the corresponding row or column (eliminates both demand and supply if both are zero).

5. Repeat step 2, 3 and 4 until all the demands and supplies are satisfied.

6. To find the minimum cost, sum of the product of the cost and the allocated values are calculated.

9. Modified Distribution Optimal Solution by Intuitionistic fuzzy Vogel's Approximation method for intuitionistic fuzzy balanced transportation problem

1. The number of allotted cells must be equal to m+n-1, if not degeneracy exists for which a very small positive assignment ϵ is allotted in independent suitable cost cell so that the number of occupied cells is exactly equal to m+n-1.

2. For each allotted cell we solve system of equations $u_i + v_j = C_{ij}$ starting with either some u_i or some v_j equating to zero where the number of allocations are maximum and hence finding the values of u_i and v_j respectively.

3. Evaluate $C_{ij}- (u_i + v_j)$ for all unoccupied cells.

4. If $d_{ij}= C_{ij}- (u_i + v_j) \geq 0$, then the basic feasible solution is the optimal solution.

10. ILLUSTRATIVE EXAMPLE 1:

Consider a 4 × 3 Heptagonal Intuitionistic Fuzzy Number with value and Ambiguity index

TABLE 1:

	D1	**D2**	**D3**	**IFS**
O1	1	2	0	⟨ (15,20,25,30,3 (10,15,20,30,40,4
O2	2	3	4	⟨ (20,25,30,35,4 (15,20,25,35,45,5
O3	1	5	6	⟨ (20,25,30,35,4 (15,20,25,35,45,5
IFD	⟨ (15,20,25,30,3 (10,15,20,30,40,4	⟨ (25,30,35,40,4 (20,25,30,40,50,5	⟨ (15,20,25,30,3 (10,15,20,30,40,4	

we apply value and ambiguity ranking on heptagonal intuitionistic fuzzy number and obtain the following crisp values [3,4,7,8,9]

Consider supply S_1 <(15,20,25,30,35,40,45)(10,15,20,30,40,45,50);0.6,0.2>

$V_\mu(S_1) = 17.9922$, $V_\vartheta(S_1) = 18.6001$, $A_\mu(S_1) = 10.612$, $A_\vartheta(S_1) = 14.917$

$V(S_1) = \frac{V_\mu(S1) + V_\vartheta(S1)}{2} = 18.2962$, $A(S_1) = \frac{A_\mu(S1) + A_\vartheta(S1)}{2} = 12.7645$

$R(S_1) = V(S_1) + A(S_1) = 31.06$

Similarly applying for all the Heptagonal intuitionistic fuzzy demand and supply values, we have the following table

TABLE 2:

	D1	D2	D3	IFA
O1	1	2	0	31.06
O2	2	3	4	34.11
O3	1	5	6	34.11
IFR	31.06	37.16	31.06	99.28

The above table 2 is a balanced transportation problem as total supply and total demand are equal to 99.28

Intuitionistic fuzzy Vogel's Approximation method for heptagonal intuitionistic fuzzy balanced transportation problem

TABLE 3: Basic Feasible Solution

	D1	D2	D3	IFS
O1	1 ∈	2	0 31.06	31.06
O2	2	3 34.11	4	34.11
O3	1 31.06	5 3.05	6	34.11
IFD	31.06	37.16	31.06	99.28

m+n-1=5, which is not equal to number of allocations 5.Hence we introduce ∈ (→0)to the unallocated least cost cell, so that m+n-1 is equal to number of allocations

Applying Modified Distribution method for optimal solution of heptagonal Intuitionistic Fuzzy transportation problem.

TABLE 4: $d_{ij} = C_{ij} - (u_i + v_j)$

	D1	D2	D3
O1	-	-3	-
O 2	3	-	6
O 3	-	-	6

Since all d_{ij} are not ≥0, we generate a loop for the improved solution

TABLE 5: $d_{ij} = C_{ij} - (u_i + v_j)$

	D1	D2	D3
O1	3	-	-
O 2	3	-	3
O 3	-	-	3

Since $d_{ij} \geq 0$, the optimality is obtained.

TABLE 6: New allocations

	D1	D2	D3	IFS
O1	1	2 ∈	0 31.06	31.06
O2	2	3 34.11	4	34.11
O3	1 31.06	5 3.05	6	34.11
IFD	31.06	37.16	31.06	99.28

Total cost = $(\in \times 2) + (31.06 \times 0) + (34.11 \times 3) + (31.06 \times 1) + (3.05 \times 5)$

$= 148.64 + 2\in$ (as $\in \rightarrow 0$)

= 148.64/-

11. CONCLUSION

A method for finding optimal solution in an intuitionistic fuzzy environment has been proposed using value and ambiguity ranking method for heptagonal intuitionistic fuzzy for cost minization transportation problem. Value and ambiguity ranking method is used to solve intuitionistic Vogel's Approximation method to find the initial basic feasible solution and modified distribution method for optimal solution of intuitionistic fuzzy transportation problem.

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