

A Novel (α , β) - Cut Based Approach for Solving Intuitionistic Fuzzy Transportation Problems Using Standard Linear Programming

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DOI: <https://doi.org/10.63001/tbs.2026.v21.i04.pp28-38>

KEYWORDS

*TIFN ,
(α , β)– cuts ,
linear programming problem.*

Article Info

Received: 16.08.2026

Accepted: 23.09.2026

Published: 06.10.2026

Abstract

In this paper a new approach to solve a transportation problem is introduced. Instead of using traditional method for a transportation problem, we convert a transportation problem into a Standard Linear Programming Problem, using (α , β) – cuts in demand and supply and solve the final LPP using any suitable method. This new approach is illustrated by a numerical example.

AMS Subject Classification:

1. Introduction

The Transportation Problem is one of the subclass of linear programming problem in which the objective is to minimize transportation cost of goods transport from various origins to different destinations. Transportation Problem firstly presented by F.L.Hitchcock [9] in his paper “The Distribution of a Product from Several sources to numerous Localities” and after that it's presenting by T. C. Koopmans[10] in his historic paper “Optimum Utilization of the

Transportation System”. These two contributions helped in the development of transportation methods which involve a number of shipping sources and a number of destinations.

A fuzzy transportation problem (FTP) is a transportation problem (TP) in which the supply and demand are fuzzy quantities. The objective of the FTP is to determine the shipping schedule that minimizes the total fuzzy transportation cost while satisfying fuzzy supply and fuzzy demand.

The concept of intuitionistic fuzzy sets (IFSs) proposed by Atanassov in 1986 is found to be highly useful to deal with vagueness. The major advantage of IFS over fuzzy set is that IFSs separate the degree of membership (belongingness) and the degree of non-membership (non-belongingness) of an element in the set

In this paper we convert the Intuitionistic Fuzzy Transportation Problem in Intuitionistic Fuzzy linear programming problem and solve this problem by using (α, β) – Level intervals and LPP Techniques. Here the supply and demand are triangular intuitionistic fuzzy numbers.

2. Preliminaries

2.1 Definition : Intuitionistic Fuzzy Set

An Intuitionistic fuzzy set (IFS) $\tilde{A}^I$ in X is given by a set of ordered triples:

$$\tilde{A}^I = \{ \langle x, \mu_{\tilde{A}^I}(x), \nu_{\tilde{A}^I}(x) \rangle / x \in X \}, \quad \text{where} \\ \mu_{\tilde{A}^I}, \nu_{\tilde{A}^I} : X \rightarrow [0, 1] \text{ are functions} \\ \text{such that } 0 \leq \mu_{\tilde{A}^I}(x) + \nu_{\tilde{A}^I}(x) \leq 1 \\ \text{for all } x \in X. \text{ For each } x \text{ the} \\ \text{numbers } \mu_{\tilde{A}^I}(x) \text{ and } \nu_{\tilde{A}^I}(x)$$

represent the degree of membership and degree of non-membership of the element $x \in X$ to $A \subset X$, respectively.

2.2 Definition : Intuitionistic Fuzzy Number

An intuitionistic fuzzy number $\tilde{A}^I$ is

- i) An intuitionistic fuzzy subset of the real line
- ii) Normal, i.e., there is any $x_0 \in R$ such that

$$\mu_{\tilde{A}^I}(x) = 1 \quad \left(\text{so that } \nu_{\tilde{A}^I}(x) = 0 \right)$$

- iii) Convex for the membership function $\mu_{\tilde{A}^I}(x)$.

$$\text{i.e. } \mu_{\tilde{A}^I}(\lambda x_1 + (1 - \lambda)x_2) \geq \min(\mu_{\tilde{A}^I}(x_1), \mu_{\tilde{A}^I}(x_2))$$

- iv) Concave for the non-membership function $\nu_{\tilde{A}^I}(x)$.

$$\text{i.e. } \nu_{\tilde{A}^I}(\lambda x_1 + (1 - \lambda)x_2) \leq \min(\nu_{\tilde{A}^I}(x_1), \nu_{\tilde{A}^I}(x_2)), x_1, x_2 \in R, \lambda \in [0, 1]$$

2.3 Definition : Triangular Intuitionistic Fuzzy Number

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

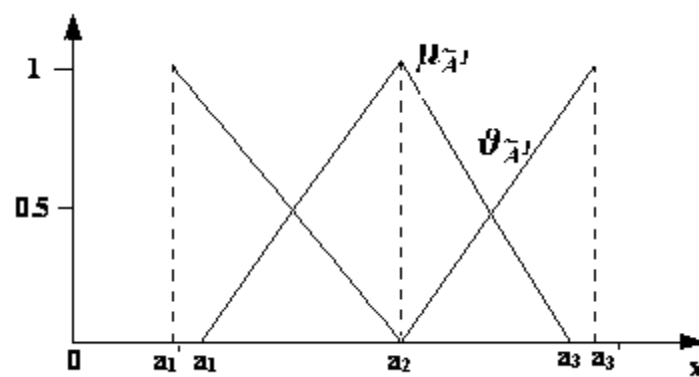
$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2 \\ \frac{x - a_3}{a_2 - a_3}, & a_2 \leq x \leq a_3 \\ 0, & \text{otherwise} \end{cases}$$

where $a_1' \leq a_1 \leq a_2 \leq a_3 \leq a_3'$ and $\mu_{\tilde{A}^I}(x) + \vartheta_{\tilde{A}^I}(x) \leq 1$, or $\mu_{\tilde{A}^I}(x) = \vartheta_{\tilde{A}^I}(x)$, for all $x \in R$.

and

$$\vartheta_{\tilde{A}^I}(x) = \begin{cases} \frac{a_2 - x}{a_2 - a_1'}, & a_1' \leq x \leq a_2 \\ \frac{x - a_2}{a_3' - a_2}, & a_2 \leq x \leq a_3' \\ 1, & \text{otherwise} \end{cases}$$

This TIFN is denoted by $\tilde{A}^I = (a_1, a_2, a_3; a_1', a_2, a_3') = \{(a_1, a_2, a_3); (a_1', a_2, a_3')\}$

Fig. Membership and non-membership functions of TIFN**2.4 Defintion : (α, β) – Level intervals or (α, β) – cuts.**

An Triangular Intuitionistic fuzzy number $\tilde{A}^I = \{(a, b, c); (e, b, f)\}$ is completely defined by its membership and non-membership function as follows:

$$L_{\mu}(x) = \frac{x-a}{b-a} \quad ; \quad a \leq x \leq b \quad \text{and} \quad R_{\mu}(x) = \frac{c-x}{c-b} \quad ; \quad b \leq x \leq c$$

$$L_{\nu}(x) = \frac{b-x}{b-e} \quad ; \quad e \leq x \leq b \quad \text{and} \quad R_{\nu}(x) = \frac{x-b}{f-b} \quad ; \quad b \leq x \leq f$$

The inverse functions L^{-1} and R^{-1} can be analytically express as given below:

$$L_{\mu}^{-1}(h) = a + (b-a)h \quad R_{\mu}^{-1}(h) = c - (c-b)h$$

$$L_{\nu}^{-1}(h) = b - (b-e)h \quad R_{\nu}^{-1}(h) = b + (f-b)h$$

Then the (α, β) – Level intervals or (α, β) – cuts denoted by $\tilde{A}^I_{\alpha, \beta}$ where $\alpha, \beta \in [0, 1]$ are fixed numbers and defined by

$$\tilde{A}^I_{\alpha, \beta} = \left[\frac{\alpha(a-c)+c+2b}{3}, \frac{2\beta(e-f)+b+2f}{3} \right]$$

3. Intuitionistic Fuzzy Linear Programming

Linear Programming with Triangular Intuitionistic Fuzzy Variables is defined as

$$(IFLP) \max \tilde{Z}^I = \sum_{j=1}^n \tilde{c}_j^I \tilde{x}_j^I$$

$$\text{Subject to } \sum_{j=1}^n \tilde{a}_{ij}^I \tilde{x}_j^I \leq \tilde{b}_i^I \quad \text{and} \quad \tilde{x}_j^I \geq 0$$

$i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$, where $\tilde{A}^I = (\tilde{a}_{ij}^I)$, $\tilde{c}^I$, $\tilde{b}^I$, $\tilde{x}^I$ are $(m \times n)$, $(1 \times n)$, $(m \times 1)$, $(n \times 1)$ intuitionistic fuzzy matrices consisting of Triangular Intuitionistic Fuzzy Numbers (TIFN).

3.1 Definition : Intuitionistic fuzzy basic feasible solution with TIFNs

Here we introduce (explore) the concept of intuitionistic fuzzy basic solution for Intuitionistic Fuzzy Variable Linear Programming (IFVLP) problems.

$$\max \tilde{Z}^I = C \tilde{x}^I \quad \dots\dots\dots (3.1)$$

$$\text{subject to } A \tilde{x}^I \leq \tilde{b}^I \quad \text{and} \quad \tilde{x}^I \geq 0 \quad \dots\dots\dots (3.2)$$

where $A = (a_{ij})$, c are $m \times n$, $1 \times n$ real matrices, $\tilde{b}^I$, $\tilde{x}^I$ are $(m \times 1)$, $(n \times 1)$ intuitionistic fuzzy matrices consisting of Triangular Intuitionistic Fuzzy Numbers (TIFN).

Let B be an $m \times m$ non-singular matrix that forms a basis for the columns of A .

It is clear that the intuitionistic fuzzy basic solution

$$\tilde{X}_B^I = (\tilde{X}_{B1}^I, \tilde{X}_{B2}^I, \dots, \tilde{X}_{Bm}^I) = B^{-1} \tilde{b}^I, \tilde{X}_N^I = \tilde{0} \quad \dots\dots\dots (3.3)$$

where $\tilde{X}_B^I$ are basic variables, $\tilde{X}_N^I$ are non-basic variables, is a solution of (3.1).

If $\tilde{X}_B^I \geq \tilde{0}$, then the intuitionistic fuzzy basic solution is feasible and the corresponding intuitionistic fuzzy objective value is $\tilde{Z}^I = c_B \tilde{X}_B^I$, where $c_B = (c_{B1}, c_{B2}, \dots, c_{Bn})$.

Now, corresponding to every index j , $1 \leq j \leq n$,

$$\text{define } z_j = c_B y_j = c_B B^{-1} a_j \quad \dots\dots\dots (3.4)$$

where a_j is the j^{th} column of the coefficient matrix A .

Observe that for any basic index $j = B_i$, $1 \leq i \leq m$, we have $B^{-1} a_j = e_i$, where $e_i = (0, 0, \dots, 0, 1, 0, \dots, 0)^T$ is the i^{th} unit vector, since $B e_i = [a_{B1}, \dots, a_{Bi}, \dots, a_{Bm}] e_i = a_{Bi} = a_j$,

And so we have $z_j - c_j = c_B B^{-1} a_j - c_j$

$$= c_B e_i - c_j = c_j - c_j = 0 \dots \dots \dots (3.5)$$

3.2 Definition : Non-degenerate intuitionistic fuzzy basic feasible solution

It is an intuitionistic fuzzy basic feasible solution in which all the m variables are positive and the remaining n variables are zero each.

3.3 Definition : Degenerate intuitionistic fuzzy basic feasible solution

It is an intuitionistic fuzzy basic feasible solution in which one or more of the m basic variables are equal to zero.

3.4 Definition : Intuitionistic fuzzy optimum feasible solution

An intuitionistic fuzzy feasible solution $\tilde{x}_0^I \in X$ is said to be an intuitionistic fuzzy optimum solution if

$$\tilde{c}^I \tilde{x}_0^I \geq \tilde{c}^I \tilde{x}^I \text{ for all } \tilde{x}^I \in X, \text{ where } \tilde{c}^I = (\tilde{c}_1^I, \tilde{c}_2^I, \tilde{c}_3^I, \dots, \tilde{c}_n^I), \text{ and}$$

$$\tilde{c}^I \tilde{x}^I = \tilde{c}_1^I \tilde{x}_1^I + \tilde{c}_2^I \tilde{x}_2^I + \tilde{c}_3^I \tilde{x}_3^I + \dots + \tilde{c}_n^I \tilde{x}_n^I \dots \dots \dots (3.7)$$

3.5 Theorem (optimality condition)

Assume the LPP with TIFN as defined in (3.1) & (3.2) is non-degenerate and B is a feasible basis. An intuitionistic fuzzy basic feasible solution $\tilde{X}_B^I = B^{-1} \tilde{b}^I, \tilde{X}_N^I = \tilde{0}$

is optimal solution to (3.1) & (3.2) if and only if $z_j - c_j \geq 0$, for all $j, 1 \leq j \leq n$.

Proof :

Suppose $\tilde{x}_*^I = ((\tilde{x}_B^I)^T, (\tilde{x}_N^I)^T)$ is an intuitionistic fuzzy basic feasible solution to (3.1),

where $\tilde{X}_B^I = B^{-1} \tilde{b}^I \geq 0, \tilde{X}_N^I = \tilde{0}$. Then the corresponding intuitionistic fuzzy objective value is

$$\tilde{z}_* \cong c \tilde{x}_* = c_B \tilde{x}_B^I = c_B B^{-1} \tilde{b}^I \dots \dots \dots (3.6)$$

On the other hand, for any intuitionistic fuzzy basic feasible solution $\tilde{x}^I$ to (3.1), we have

$$\tilde{b}^I = A \tilde{x}^I = B \tilde{X}_B^I + N \tilde{X}_N^I$$

Hence, we can rewrite (3.7) as follows :

$$\tilde{X}_B^I = B^{-1} \tilde{b}^I - B^{-1} N \tilde{X}_N^I \dots \dots \dots (3.8)$$

Then for any intuitionistic fuzzy basic feasible solution to (3.1), we have

$$\begin{aligned} \tilde{z}^I &= c \tilde{x}^I \\ &= c_B \tilde{X}_B^I + c_N \tilde{X}_N^I \\ &= c_B B^{-1} \tilde{b}^I - (c_B B^{-1} N - c_N) \tilde{X}_N^I \end{aligned}$$

$$\begin{aligned}
 &= c_B \ B^{-1} \ \bar{b}^I - \sum_{j=1}^n (c_B \ B^{-1} a_j - c_j) \bar{x}_j^I \\
 &= c_B \ B^{-1} \ \bar{b}^I - \sum_{j=1}^n (z_j - c_j) \bar{x}_j^I
 \end{aligned}$$

Hence using (3.5) & (3.6) , we have

$$\tilde{Z}^I = \tilde{Z}^I - \sum_{j \neq B_i} (Z_j - C_j) \tilde{x}_j^I \quad \dots\dots\dots(3.9)$$

Now, if for all j , $1 \leq j \leq n$, we have $z_j \geq c_j$, then from feasibility of $\tilde{x}^I$ we have

$$(z_j - c_j) \bar{x}_j^I \geq \bar{0}^I, \text{ and then we obtain } \sum_{j \neq B_i} (z_j - c_j) \bar{x}_j^I \geq \bar{0}^I.$$

Therefore , it follows from (3.9) that $\tilde{z}^I \leq \tilde{z}^I$ and so $\tilde{x}^I$ is optimal.

For only if part :

Let $\tilde{x}^I$ be an intuitionistic fuzzy optimal basic feasible solution to (3.1).

For $j = B_i$, $1 \leq i \leq m$, from (3.5) , we know that $z_j - c_j = 0$.

From (3.9) , it is obvious that for any non-basic variable $\tilde{x}_j^I$, we have $z_j < c_j$, then

we can enter $\tilde{x}_j^I$ into the basis and obtain $\tilde{z}^I > \tilde{z}^I$ (because the problem is non-degenerate and $\tilde{x}_j^I \geq \bar{0}^I$ in the new basis). This is a contradiction to $\tilde{z}^I$ being optimal.

Hence we have $z_j \geq c_j$, $1 \leq j \leq n$.

Hence the proof

4. Converting the Intuitionistic Fuzzy transportation problem in Intuitionistic Fuzzy linear programming problem

Consider the following Intuitionistic Fuzzy Transportation Problem

	D1	D2	D3	Demand
O1	5	4	3	(6,10,13;4,10,15)
O2	8	4	3	(25,30,34;22,30,37)
O3	9	7	5	(27,30,36;23,30,40)

Supply (28,30,34;24,30,30) (17,20,23;15,20,25) (13,20,26;10,20,31)

Now we are converting the transportation problem into a Linear Programming Problem as follows :

Maximize $Z = 5X_{11} + 4X_{12} + 3X_{13} + 8X_{21} + 4X_{22} + 3X_{23} + 9X_{31} + 7X_{32} + 5X_{33}$

Subject to constraint:

$$X_{11} + X_{12} + X_{13} = (6,10,13;4,10,15)$$

$$X_{21} + X_{22} + X_{23} = (25,30,34;22,30,37)$$

$$X_{31} + X_{32} + X_{33} = (27,30,36;23,30,40)$$

$$X_{11} + X_{21} + X_{31} = (28,30,34;24,30,30)$$

$$X_{12} + X_{22} + X_{32} = (17,20,23;15,20,25)$$

$$X_{13} + X_{23} + X_{33} = (13,20,26;10,20,31)$$

$$X_{11}, X_{12}, X_{13}, X_{21}, X_{22}, X_{23}, X_{31}, X_{32}, X_{33} \geq 0$$

Using (α, β) – Level intervals or (α, β) – cuts we reduce the above LPP as given below:

$$X_{11} + X_{12} + X_{13} = \left(\frac{33-7\alpha}{3}; \frac{40-22\beta}{3} \right)$$

$$X_{21} + X_{22} + X_{23} = \left(\frac{94-9\alpha}{3}; \frac{104-30\beta}{3} \right)$$

$$X_{31} + X_{32} + X_{33} = \left(\frac{96-9\alpha}{3}; \frac{110-34\beta}{3} \right)$$

$$X_{11} + X_{21} + X_{31} = \left(\frac{94-6\alpha}{3}; \frac{102-24\beta}{3} \right)$$

$$X_{12} + X_{22} + X_{32} = \left(\frac{63-6\alpha}{3}; \frac{70-20\beta}{3} \right)$$

$$X_{13} + X_{23} + X_{33} = \left(\frac{66-13\alpha}{3}; \frac{82-42\beta}{3} \right)$$

The constraints are divided into two categories namely equations containing α (membership values) and equations containing β (non – membership values) :

$X_{11} + X_{12} + X_{13} = \frac{33-7\alpha}{3}$	$X_{11} + X_{12} + X_{13} = \frac{40-22\beta}{3}$
$X_{21} + X_{22} + X_{23} = \frac{94-9\alpha}{3}$	$X_{21} + X_{22} + X_{23} = \frac{104-30\beta}{3}$
$X_{31} + X_{32} + X_{33} = \frac{96-9\alpha}{3}$	$X_{31} + X_{32} + X_{33} = \frac{110-34\beta}{3}$
$X_{11} + X_{21} + X_{31} = \frac{94-6\alpha}{3}$	$X_{11} + X_{21} + X_{31} = \frac{102-24\beta}{3}$
$X_{12} + X_{22} + X_{32} = \frac{63-6\alpha}{3}$	$X_{12} + X_{22} + X_{32} = \frac{70-20\beta}{3}$

$X_{13} + X_{23} + X_{33} = \frac{66-13\alpha}{3}$	$X_{13} + X_{23} + X_{33} = \frac{82-42\beta}{3}$
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By substituting $\alpha = 0$ and $\beta = 1$ we get a special case :

$X_{11} + X_{12} + X_{13} = \frac{33}{3}$	$X_{11} + X_{12} + X_{13} = \frac{18}{3}$
$X_{21} + X_{22} + X_{23} = \frac{94}{3}$	$X_{21} + X_{22} + X_{23} = \frac{74}{3}$
$X_{31} + X_{32} + X_{33} = \frac{96}{3}$	$X_{31} + X_{32} + X_{33} = \frac{76}{3}$
$X_{11} + X_{21} + X_{31} = \frac{94}{3}$	$X_{11} + X_{21} + X_{31} = \frac{78}{3}$
$X_{12} + X_{22} + X_{32} = \frac{63}{3}$	$X_{12} + X_{22} + X_{32} = \frac{50}{3}$
$X_{13} + X_{23} + X_{33} = \frac{66}{3}$	$X_{13} + X_{23} + X_{33} = \frac{40}{3}$

On solving this Linear Programming Formulation of Transportation Problem we get the optimal solution as:

values	Constraints	Optimum solution in interval	Optimum solution
$\alpha = 0$ and $\beta = 1$	$X_{13}=11; X_{21}=31.33; X_{22}=0;$ $X_{32}=21; X_{33}=11$	(485.64 , 380.67)	433.155
	$X_{13}=6; X_{21}=24.67$; $X_{31}=1.33;$ $X_{32}=16.67; X_{33}=7.33$		

A table containing optimal solution in interval and obtained solution in crisp values for various α and β values in given below :

values	Constraints	Optimum solution in interval	Optimum solution
$\alpha = 0.5$ and $\beta = 0.5$	$X_{13}=9.83; X_{21}=29.83; X_{31}=0.5;$ $X_{32}=20; X_{33}=10$	(462.63 , 462.66)	462.645

	$X_{13}=9.66; X_{21}=29.67; X_{31}=0.33;$ $X_{32}=20; X_{33}=10.67$		
$\alpha = 1$ and $\beta = 0$	$X_{13}=8.67; X_{21}=28.33; X_{31}=1;$ $X_{32}=19; X_{33}=9$	(439.65 , 543.98)	491.815
	$X_{13}=13.33; X_{21}=34; X_{23}=0.66;$ $X_{32}=23.33; X_{33}=13.34$		
$\alpha = 0.25$ and $\beta = 0.75$	$X_{13}=10.42; X_{21}=30.58; X_{31}=0.25;$ $X_{32}=20.50; X_{33}=10.5$	(474.15 , 421.7)	447.925
	$X_{13}=7.83; X_{21}=27.17; X_{31}=0.83;$ $X_{32}=18.34; X_{33}=9$		
$\alpha = 0.75$ and $\beta = 0.25$	$X_{13}=9.25; X_{21}=29.08; X_{31}=0.75;$ $X_{32}=19.5; X_{33}=9.5$	(451.14 , 503.5)	477.32
	$X_{13}=11.5; X_{21}=32; X_{23}=0.17;$ $X_{32}=21.67; X_{33}=12.16$		

Conclusion

The approach to solve a Transportation Problem using LPP and (α, β) - cuts pave a new path way in solving Transportation Problems. This idea can be further strengthened and more improved feasible solution in less iterations may be obtained.

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