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# The Signature Method for Solving Intuitionistic Fuzzy Assignment Problems

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**ABSTRACT**

The Assignment Problem is one of the most studied, well known and important problem in Mathematics and is used very often in solving problems of engineering and management sciences. It is one of the fundamental combinatorial optimization problems in the field of Operations Research. It is a particular case of transportation problem where the objective is to assign the resources to the activities so as to minimize total cost or maximize total profit of allocation. In this paper, we proposed the signature method for solving intuitionistic fuzzy assignment problems.

***Keywords:*** Assignment problem, intuitionistic fuzzy numbers, generalized trapezoidal intuitionistic fuzzy numbers, ranking of fuzzy numbers, signature of a tree

***Mathematical Subject Classification (2010):*** 90B80

## 1. Introduction

The assignment problem is a special type of linear programming problem in which our objective is to assign $n$ number of jobs to $n$ number of persons at a minimum cost or a maximum profit. Assignment may be persons to jobs, classes to rooms, operators to machines, drivers to trucks, trucks to delivery routes, or problems to research teams etc. To find solutions to assignment problems, various algorithms such as linear programming, Hungarian algorithm, neural network and genetic algorithm have been developed. Over the past 50 years, many variations of the classical assignment problems are proposed, e.g., bottleneck assignment problem, quadratic assignment problem etc. Lin and Wen [5] proposed an efficient algorithm based on the labeling method for solving the linear fractional programming case. Sakawa et al. [8] solved the problems on production and work force assignment in a firm using interactive fuzzy programming for two level linear and linear fractional programming models. Chen [3] projected a fuzzy assignment model that considers all persons to have same skills. Hsuan and Wen [4] developed a procedure for solving assignment problems with multiple inadequate inputs and outputs in crisp form for each possible assignment using linear programming model to determine the assignments with maximum efficiency. Liu and Gao [6] considered the genetic algorithm for solving the fuzzy weighted equilibrium and multi-job assignment problem.

Majumdar and Bhunia [7] developed an exclusive genetic algorithm to solve a generalized assignment problem with imprecise cost(s)/time(s), in which the impreciseness of cost(s)/time(s) are represented by interval valued numbers. Ye and Xu [15] developed a priority based genetic algorithm to a fuzzy vehicle routing assignment model with connection network. Mukherjee and Basu [12] developed a method for solving intuitionistic fuzzy assignment problems by using similarity measures and score function. Pandian and Kavitha [11], Jose and Kuriakose [13], Thorani and Shankar [14], and Nirmala and Anju [10] developed various algorithms for solving assignment problems in the fuzzy context. Here we are considering assignment problems having generalized trapezoidal intuitionistic fuzzy numbers as costs or profits. We apply a ranking method [9] defined on generalized intuitionistic trapezoidal fuzzy numbers to rank the fuzzy costs present in the assignment problem.

This paper is organized as follows. In section 2, we present the basic concepts of intuitionistic fuzzy numbers, generalized trapezoidal intuitionistic fuzzy numbers and its arithmetic operations. In section 3, a ranking method is given to rank the generalized trapezoidal intuitionistic fuzzy numbers. In section 4, the mathematical formulation of intuitionistic fuzzy optimal assignment problem is reviewed. The signature method for solving an assignment problem with costs as generalized trapezoidal intuitionistic fuzzy numbers is presented in section 5. In section 6, a numerical example is presented to show the application of the proposed algorithm. Finally, the conclusion is given in section 7.

## 2. Preliminary concepts

### 2.1. Intuitionistic fuzzy sets and intuitionistic fuzzy numbers

In this section we will review the basic concepts of intuitionistic fuzzy sets and intuitionistic fuzzy numbers.

**Definition 2.1.1.** [1, 2] Let X be the universal set. An intuitionistic fuzzy set (IFS) A in X is given by

$$A = \{(x, \mu_A(x), \nu_A(x)) : x \in X\}$$

where the functions $\mu_A(x), \nu_A(x)$ define respectively, the degree of membership and degree of non-membership of the element $x \in X$ to the set $A$, which is a subset of $X$, and for every $x \in X$, $0 \leq \mu_A(x) + \nu_A(x) \leq 1$.

**Definition 2.1.2.** An IFS $A = \{(x, \mu_A(x), \nu_A(x)) : x \in X\}$ of the real line $\mathbb{R}$ is called an intuitionistic fuzzy number (IFN) if

a) A is convex for the membership function $\mu_A(x)$, i.e., if
$$\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \mu_A(x_1) \wedge \mu_A(x_2)$$
for all $x_1, x_2 \in \mathbb{R}$, $\lambda \in [0, 1]$.

b) A is concave for the non-membership function $\nu_A(x)$, i.e., if
$$\nu_A(\lambda x_1 + (1-\lambda)x_2) \leq \nu_A(x_1) \vee \nu_A(x_2)$$
for all $x_1, x_2 \in \mathbb{R}$, $\lambda \in [0, 1]$.

c) A is normal, that is, there is some $x_0 \in \mathbb{R}$ such that $\mu_A(x_0) = 1$ and $\nu_A(x_0) = 0$.

**Definition 2.1.3.** (**Generalized trapezoidal intuitionistic fuzzy number**) An intuitionistic fuzzy number A is said to be a generalized trapezoidal intuitionistic fuzzy number (GTIFN) with parameters

$$b_1 \le a_1 \le b_2 \le a_2 \le a_3 \le b_3 \le a_4 \le b_4,$$

and denoted by

$A = (b_1, a_1, b_2, a_2, a_3, b_3, a_4, b_4; \omega_A, u_A)$ or $A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4); \omega_A, u_A)$ if its membership and non-membership functions are as follows:

$$\begin{aligned}
\mu_A(x) &= 0 && \text{if} \quad x < a_1 \\
&= \omega_A\left(\frac{x - a_1}{a_2 - a_1}\right) && \text{if} \quad a_1 \le x \le a_2 \\
&= \omega_A && \text{if} \quad a_2 \le x \le a_3 \\
&= \omega_A\left(\frac{a_4 - x}{a_4 - a_3}\right) && \text{if} \quad a_3 \le x \le a_4 \\
&= 0 && \text{if} \quad x > a_4
\end{aligned}$$

and

$$\begin{aligned}
\nu_A(x) &= 1 && \text{if} \quad x < b_1 \\
&= \frac{(b_2 - x) + u_A(x - b_1)}{b_2 - b_1} && \text{if} \quad b_1 \le x \le b_2 \\
&= u_A && \text{if} \quad b_2 \le x \le b_3 \\
&= \frac{(x - b_3) + u_A(b_4 - x)}{b_4 - b_3} && \text{if} \quad b_3 \le x \le b_4 \\
&= 1 && \text{if} \quad x > b_4.
\end{aligned}$$

where $0 < \omega_A \le 1, 0 \le u_A \le 1$ and $0 < \omega_A + u_A \le 1$.

If $b_1 = a_1, b_2 = a_2,\ b_3 = a_3,\ b_4 = a_4,$ then the corresponding intuitionistic fuzzy number is of the form

$$A = ((a_1, a_2, a_3, a_4); \omega_A, u_A)$$

## 2.2. Arithmetic operations on generalized trapezoidal intuitionistic fuzzy numbers

Let

$$A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4); \omega_A, u_A)$$

and

$$B = ((c_1, c_2, c_3, c_4), (d_1, d_2, d_3, d_4); \omega_B, u_B)$$

be two GTIFNs and $\lambda$ be a real number. Then

(***i***) $A + B = ((a_1 + c_1, a_2 + c_2, a_3 + c_3, a_4 + c_4), (b_1 + d_1, b_2 + d_2, b_3 + d_3, b_4 + d_4);\ \omega, u)$

where $\omega = \min\{\omega_A, \omega_B\}$ and $u = \max\{u_A, u_B\}$.

(***ii***) $A - B = ((a_1 - c_4, a_2 - c_3, a_3 - c_2, a_4 - c_1), (b_1 - d_4, b_2 - d_3, b_3 - d_2, b_4 - d_1);\ \omega, u)$

where $\omega = \min\{\omega_A, \omega_B\}$ and $u = \max\{u_A, u_B\}$.

(***iii***) $\lambda A = ((\lambda a_1, \lambda a_2, \lambda a_3, \lambda a_4), (\lambda b_1, \lambda b_2, \lambda b_3, \lambda b_4); \omega_A, u_A)$ if $\lambda > 0$

$= ((\lambda a_4, \lambda a_3, \lambda a_2, \lambda a_1), (\lambda b_4, \lambda b_3, \lambda b_2, b a_1); \omega_A, u_A)$ if $\lambda < 0$.

## 3. Ranking of generalized trapezoidal intuitionistic fuzzy numbers

The ranking order relation between two GTIFNs is a difficult problem. However, GTIFNs must be ranked before the action is taken by the decision maker. In this paper we are using the following method for ranking generalized trapezoidal intuitionistic fuzzy numbers.

If $A = ((a_1, a_2, a_3, a_4), (b_1, b_2, b_3, b_4); \omega_A, u_A)$, then

$$\Re(A) = \frac{\omega_A S(\mu_A) + u_A S(\nu_A)}{\omega_A + u_A},$$

where

$$S(\mu_A) = \left(\frac{2a_1 + 7a_2 + 7a_3 + 2a_4}{18}\right)\left(\frac{7\omega_A}{18}\right) \text{ and } S(\nu_A) = \left(\frac{2b_1 + 7b_2 + 7b_3 + 2b_4}{18}\right)\left(\frac{11 + 7u_A}{18}\right).$$

If $A = ((a_1, a_2, a_3, a_4); \omega_A, u_A)$, then

$$S(\mu_A) = \left(\frac{2a_1 + 7a_2 + 7a_3 + 2a_4}{18}\right)\left(\frac{7\omega_A}{18}\right) \text{ and } S(\nu_A) = \left(\frac{2a_1 + 7a_2 + 7a_3 + 2a_4}{18}\right)\left(\frac{11 + 7u_A}{18}\right).$$

## 4. Intuitionistic fuzzy assignment problems

Suppose there are ***n*** jobs to be performed and ***n*** persons are available for doing the jobs. Assume that each person can do each job at a time, depending on their efficiency to do the job. Let $\tilde{c}_{ij}$ be the intuitionistic fuzzy cost if the $i^{th}$person is assigned the $j^{th}$job. The objective is to minimize the total intuitionistic fuzzy cost of assigning all the jobs to the available persons (one job to one person).

The intuitionistic fuzzy assignment problem can be stated in the form of an $n \times n$ cost matrix $[\tilde{c}_{ij}]$ of intuitionistic fuzzy numbers as given in the following table:

| Persons | Jobs | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | …. | N |
| 1 | $\tilde{c}_{11}$ | $\tilde{c}_{12}$ | $\tilde{c}_{13}$ | …. | $\tilde{c}_{1n}$ |
| 2 | $\tilde{c}_{21}$ | $\tilde{c}_{22}$ | $\tilde{c}_{23}$ | …. | $\tilde{c}_{2n}$ |
| ⋮ | | | | | |
| n | $\tilde{c}_{n1}$ | $\tilde{c}_{n2}$ | $\tilde{c}_{n3}$ | …. | $\tilde{c}_{nn}$ |

Mathematically an intuitionistic fuzzy assignment problem can be stated as

Minimize $\tilde{z} = \sum_{i=1}^{n} \sum_{j=1}^{n} \tilde{c}_{ij} x_{ij}$

Subject to

$$\sum_{j=1}^{n} x_{ij} = 1, i = 1,2, \dots n.$$
$$\sum_{i=1}^{n} x_{ij} = 1, j = 1,2, \dots n.$$

where

$$x_{ij} = 1, \quad \text{if the } i^{th} \text{ person is assigned the } j^{th} \text{ job}$$
$$= 0, \text{ otherwise}$$

is the decision variable denoting the assignment of the person $i$ to job $j$. $\tilde{c}_{ij}$ is the cost of assigning the $j^{th}$ job to the $i^{th}$ person. Here each $\tilde{c}_{ij}$is a generalized trapezoidal intuitionistic fuzzy number.

**5. The signature method**

Consider an $n \times n$ intuitionistic fuzzy assignment problem with cost matrix $\tilde{\boldsymbol{c}} = [\tilde{c}_{ij}]$. Let the set of $n$ nodes $R$ represent the rows of the matrix, the set of $n$ nodes $C$ represent the columns. Hence to solve the problem, we have to find a permutation $\sigma$ of the column indices that minimizes $\sum_{i=1}^{n} \tilde{c}_{i\sigma(i)}$.

Let $T$ be any spanning tree of edges $(i,j), i \in R, j \in C$, containing exactly $2n-1$ edges. Given any $T$, unique values of $u_i$ and $v_j$ that solve the equations

$$u_i + v_j = \Re(\tilde{c}_{ij})$$

for$(i,j) \in T$ may be computed as follows:

($\boldsymbol{i}$) Set $u_1 = 0$;

($\boldsymbol{ii}$) If $(i,j) \in T$ and $i$ has value $u_i$, define $v_j = \Re(\tilde{c}_{ij}) - u_i$;
If $(i,j) \in T$ and $j$ has value $v_j$, define $u_i = \Re(\tilde{c}_{ij}) - v_j$.

If in addition, $u_i + v_j \leq \Re(\tilde{c}_{ij})$ for $(i,j) \notin T$, then $\boldsymbol{u}, \boldsymbol{v}$,where

$$\boldsymbol{u} = (u_1, u_2, \ldots, u_n)$$

and

$$\boldsymbol{v} = (v_1, v_2, \ldots, v_n),$$

and its $T = T(\boldsymbol{u}, \boldsymbol{v})$is said to be ***feasible***. Then the method is based on the following theorem.

**Theorem 5.1.** If $T(\boldsymbol{u}, \boldsymbol{v})$ is a feasible spanning tree with some row node $i^*$ of degree 1 and the remaining rows of degree 2, then the permutation $\sigma$ defined as follows solves the assignment problem:

$$\sigma(i^*) = j \quad \text{for} \quad (i^*, j) \in T(\boldsymbol{u}, \boldsymbol{v})$$

$\sigma(i) = j \quad , i \neq i^*$, for $(i,j) \in T(\boldsymbol{u}, \boldsymbol{v})$, the unique edge incident to $i$ not on the path joining $i$ to $i^*$.

**Definition 5.1.** The *signature* of a tree $T$ is the vector of its row node degrees

$$\boldsymbol{a} = (a_1, a_2, \ldots, a_n), \sum_{i=1}^{n} a_i = 2n - 1, a_i \geq 1$$

for all $i$.

A tree is said to be in level $k$, if its signature has exactly $k$ 1's. This method seeks a tree whose signature contains exactly one 1 and otherwise 2's.

**5.1. The proposed algorithm**

We perform the following steps for solving the assignment problem.

**Step 1:** Let $T$ be any spanning tree of edges $(i,j), i \in R, j \in C$ containing exactly $2n-1$ edges.

**Step 2:** Compute unique values of $u_i$ and $v_j$ that solve the equations $u_i + v_j = \Re(\tilde{c}_{ij})$, for $(i,j) \in T$ as follows:

($\boldsymbol{i}$) Set $u_1 = 0$;

($\boldsymbol{ii}$) If $(i,j) \in T$ and $i$ has value $u_i$, define $v_j = \Re(\tilde{c}_{ij}) - u_i$;
If $(i,j) \in T$ and $j$ has value $v_j$, define $u_i = \Re(\tilde{c}_{ij}) - v_j$.

[To get the initial spanning $T$ feasible, we take $u_1 = 0$, $v_j = \Re(\tilde{c}_{1j})$, $j \in C$ and $(1,j) \in T$ for every $j \in C$; and $u_i = \min_j\{\Re(\tilde{c}_{ij}) - \Re(\tilde{c}_{1j})\}$, $1 \neq i \in R$ and $(i,j) \in T$ for one $j$ that gives the minimum]

**Step 3:** Find the signature $\boldsymbol{a}$ of $T$. If $\boldsymbol{a}$ contains exactly one 1 and otherwise 2's, stop. To get the optimal assignment go to Step 7. If not, go to Step 4.

**Step 4:** Find an edge $(k, l) \in T(\boldsymbol{u}, \boldsymbol{v})$, where both $k$ and $l$ having degree at least 2, and drop $(k, l)$. This cuts $T$ into two distinct components: $T^k$, which contains $k \in R$, and $T^l$, which contains $l \in C$. Let

$$\delta = \min\{\Re(\tilde{c}_{ij}) - u_i - v_j; i \in T^l, j \in T^k\},$$

and $(g, h)$ be some pair at which the minimum is achieved. Then $(g, h)$ is the incoming edge.

**Step 5:** Define the neighboring tree $T'$ by

$$T' = T^k \cup T^l \cup (g, h),$$

and,

$$u_i' = u_i + \delta, i \in T^l, u_i' = u_i \text{ otherwise,}$$
$$v_j' = v_j - \delta, j \in T^l, v_j' = v_j \text{ otherwise.}$$

Since $\delta \geq 0$ because $T$ is feasible, $T'$ is also feasible.

**Step 6**: Find the signature $\boldsymbol{a}'$of $T'$. The signature $\boldsymbol{a}'$of $T'$ is the same as that of $T$ except that $a_k' = a_k - 1$ and $a_g' = a_g + 1$. If $\boldsymbol{a}'$ contains exactly one 1 and otherwise 2's, stop. To get the optimal assignment go to Step 7. If not, repeat Steps 4 and 5 for $T'$ until we get a spanning tree, say $T^n$, with the required signature and then go to Step 7.

**Step 7**: If $i^*$ is the row node of degree 1 in $T^n$, then the permutation $\sigma$ defined as follows solves the assignment problem:

$$\sigma(i^*) = j \quad \text{for} \quad (i^*, j) \in T^n$$

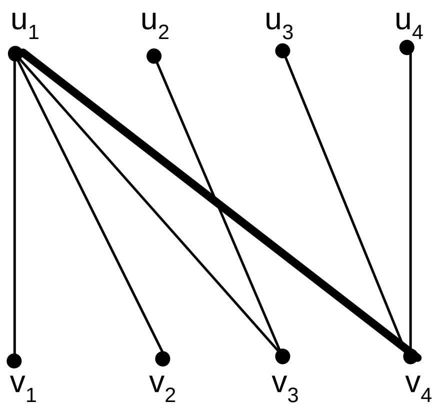
$\sigma(i) = j \quad, i \neq i^*$, for $(i, j) \in T^n$, the unique edge incident to $i$ not on the path joining $i$ to $i^*$.

## 6. Numerical example

To illustrate the proposed method, let us consider an intuitionistic fuzzy assignment problem with 4 persons and 4 jobs, where in the cost matrix $[\tilde{c}_{ij}]$the rows representing 4 persons A, B, C, D and columns representing the 4 jobs Job1, Job2, Job3 and Job4. The entries of the cost matrix $[\tilde{c}_{ij}]$ are generalized trapezoidal intuitionistic fuzzy numbers. The problem is to find an optimal assignment so that the total cost of job assignment becomes minimum.

| Persons | Jobs | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| A | ((3,5,6,8), (2,4,7,10); 0.6,0.1) | ((5, 8, 11, 13), (4,6,12,14); 0.7,0.2) | ((8, 10, 11, 15), (7,9,13,17); 0.5,0.3) | ((5, 8, 10, 12), (4,7,11,13); 0.5,0.3) |
| B | ((7, 9, 10, 12), (6,8,11,13); 0.7,0.1) | ((3, 5, 6,8), (1,4,7,10); 0.4,0.3) | ((6, 8, 10, 12), (5,7,11,13); 0.7,0.1) | ((5, 8, 10, 12), (4,6,11,13); 0.8,0.1) |
| C | ((2, 4, 5,7 ), (1,3,6,8); 0.6,0.1) | ((5, 7, 10, 12), (4,6,11,14); 0.7,0.1) | ((8, 11, 13, 15), (7,9,14,16); 0.6,0.2) | ((4, 6, 7, 10), (2,5,8,11); 0.8,0.1) |
| D | ((6, 8, 10, 12), (5,7,11,13); 0.8,0.1) | ((2, 5, 6, 8), (1,3,7,9); 0.7,0.1) | ((5, 7, 10, 14), (4,6,12,15); 0.6,0.2) | ((2, 4, 5, 7), (1,3,6,8); 0.7,0.1) |

**Solution:** Let the set of 4 nodes $R$ represent the rows of the matrix, the set of 4 nodes $C$ represent the columns, and consider the following spanning tree $T$ of edges $(i,j), i \in R, j \in C$.




Set$u_1 = 0$. Then $\boldsymbol{v} = (v_1, v_2, v_3, v_4)$

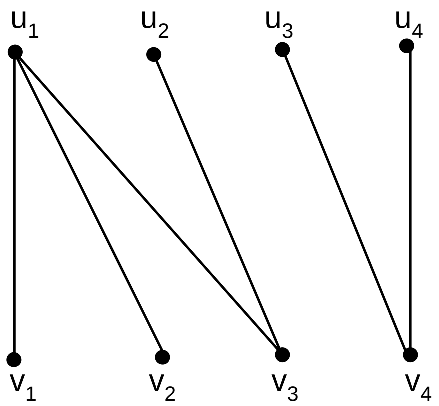
$= (\Re(\tilde{c}_{11}), \Re(\tilde{c}_{12}), \Re(\tilde{c}_{13}), \Re(\tilde{c}_{14}))$=(1.621,3.366,4.366,3.506),
since $(1,j) \in T$ for every $j \in C$. Also $\Re(\tilde{c}_{ij})$ is calculated by using the ranking method given in Section 3. To become $T$ feasible, choose

$$u_i = \min_j\{\Re(\tilde{c}_{ij}) - \Re(\tilde{c}_{1j})\},\ 1 \neq i \in R \text{ and } (i,j) \in T.$$

Thus

$$\boldsymbol{u} = (u_1, u_2, u_3, u_4) = (0, -1.491, -1.208, -2.068).$$

Now the signature of $T$ is $\mathbf{a} = (4,1,1,1)$. Since $\mathbf{a}$ is not of the required type, we move to the neighboring tree $T'$ by pivoting on the edge $(k,l) = (1,4) \in T(\boldsymbol{u}, \boldsymbol{v})$, drop $(k,l) = (1,4)$. This cuts $T$ into two distinct components: $T^k$, which contains $k = 1 \in R$, and $T^l$, which contains $l = 4 \in C$.

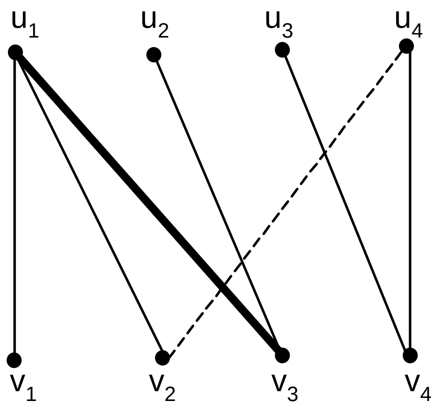



Let

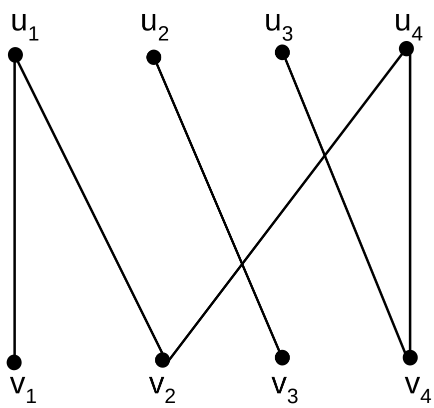
$$\delta = \min\{\Re(\tilde{c}_{ij}) - u_i - v_j; i \in T^l, j \in T^k\}$$

$$= \{0.905, 0.566, 0.903, 3.586, 0.392, 0.798\} = 0.392$$

and$(g,h) = (4,2)$ be the pair at which the minimum is achieved. Then $(g,h) = (4,2)$ is the incoming edge. Hence the new feasible spanning tree $T'$ is:



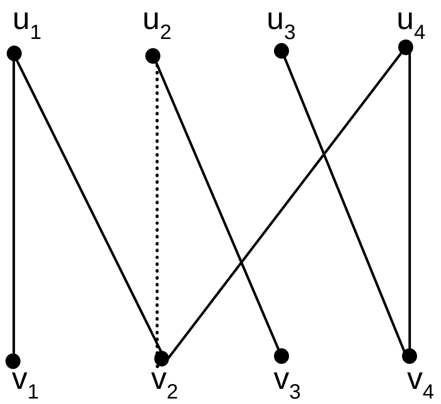

For the tree $T'$, $\boldsymbol{u} = (0, -1.491, -0.816, -1.676)$, $\boldsymbol{v} = (1.621, 3.366, 4.366, 3.114)$and signature is $\mathbf{a}' = (3,1,1,2)$. Since $\mathbf{a}'$ is not of the required type, we move to the neighboring tree $T''$ by pivoting on the edge $(k,l) = (1,3) \in T'(\boldsymbol{u},\boldsymbol{v})$, drop $(k,l) = (1,3)$. This cuts $T'$ into two distinct components: $T^k$, which contains $k = 1 \in R$, and $T^l$, which contains $l = 3 \in C$.



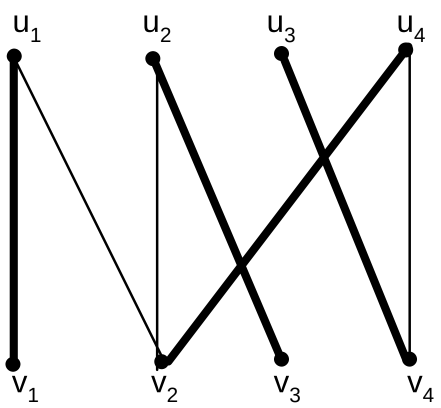

Let

$$\delta = \min\{\Re(\tilde{c}_{ij}) - u_i - v_j; i \in T^l, j \in T^k\}$$
$$= \{2.905, 0.329, 1.449\} = 0.329$$

and $(g,h) = (2,2)$ be the pair at which the minimum is achieved. Then $(g,h) = (2,2)$ is the incoming edge. Hence the new feasible spanning tree $T''$ is:




For the tree $T''$,signature is $\mathbf{a}'' = (2,2,1,2)$, which is of the required type. Hence we get the optimal assignment from $T''$. By using Theorem 5.1, the optimal assignment is as follows:




So the optimal assignment is

$$A \rightarrow 1, B \rightarrow 3, C \rightarrow 4, D \rightarrow 2$$

## 7. Conclusion

In this paper, a new method has been developed for solving assignment problems with costs as generalized trapezoidal intuitionistic fuzzy numbers by using the given ranking method. There are several papers in the literature for solving assignment problems with intuitionistic fuzzy costs, but no one has used generalized intuitionistic fuzzy costs. The method is easy to understand and can be used for all types of assignment problems with costs as fuzzy as well as intuitionistic fuzzy numbers.

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