Neutrosophic Sets and Systems, Vol. 64, 2024
University of New Mexico

On Solving Bi-objective Interval Valued Neutrosophic Assignment Problem

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Abstract: The assignment problem (AP) is a well-researched combinatorial optimization problem in which the overall assignment cost or time is minimized by assigning multiple items (tasks) to several entities (workers). Today's optimization challenges cannot be adequately addressed by a single-objective AP, hence the bi-objective AP (BOAP) is taken into consideration. This problem frequently occurs in practical applications with ambiguous parameters in real life. Henceforth, in this article the uncertain parameters are presented as interval valued neutrosophic numbers. In the present study, we formulate bi-objectives assignment problem (BOAP) having cost and time parameters as an interval valued neutrosophic numbers. We proposed interactive left-width method to solve the interval valued neutrosophic BOAP (IVNBOAP). In this method interval valued neutrosophic numbers is reduced to interval numbers using score function. Then, the bi-objective interval assignment problem (BOIAP) is reduced to a deterministic BOAP using the left-width attributes on each objective function. The reduced deterministic objective function is separated and constructed as a multi-objective AP. In the solution procedure, the global weighted sum method is adopted to convert the multi-objective AP into a single objective problem (SOP) and solved using Lingo 18.0 software. Finally, numerical examples are illustrated to clarify the steps involved in the proposed method and results are compared with the other existing methods.

Keywords: Interval Assignment Problem, Interval-valued Neutrosophic Numbers, Interactive Left-Width Method, Optimal Compromise Solution, Global Weighted Sum Method.

1. Introduction

In the AP, the objective is to distribute several tasks to an equal number of machines, people or facilities with optimal decision parameters. From the existing literature, it can be seen that several researchers have come up with different methods to resolve AP[1–3]. In all these studies, it is noted that actual deterministic numbers are used for effectual matrices of the relevant AP. In real-life situations, the elements of the effectual matrices of AP are an imprecise number than deterministic, due to the limited knowledge of personnel on problem domain, lack of data, inaccurate estimates, etc. This inexact information on decision parameters is expressed by interval numbers or fuzzy numbers or intuitionistic numbers or neutrosophic numbers. In recent years, numerous experts [4–7] have conducted thorough studies on the interval AP. When the boundary of this interval is ambiguous, that interval is a fuzzy set. In 1965, Lotfi Zadeh introduced fuzzy set theory, which was developed to provide formalized techniques for addressing imprecision through varying degrees of membership and to mathematically

describe uncertainty. Various researchers such as Gupta et al.[8] , Thorani and Shankar [9], Baidya and Bera [10] , Buvaneshwari and Anuradha [11] have utilized the various methods for solving fuzzy TP/AP to determine the optimal/ optimal compromise solution.
The fuzzy set (FS) deals with uncertainty, but hesitation is also taken into consideration in a real-life problem. Atanassov [12] has extended FS to intuitionistic FS (IFS) by including hesitation as a non-membership degree. An IFS can be a realistic and relevant tool in dealing with problems having both uncertainty and hesitation. An accuracy function was applied by Ebrahimnejad and Verdegay [13] and Mahmoodirad et al. [14] to solve the intuitionistic fuzzy transportation problem (IFTP). Roy et al. [15] proposed the intuitionistic fuzzy programming approach (IFPA) and goal programming approach (GPA) to solve the intuitionistic fuzzy multi-objective transportation problem (IFMOTP). Bharati [16] has discussed TP with interval-valued IFS influence of a new ranking. Mahajan and Gupta [29] utilized a variety of membership functions (MFs) to solve fully IFMOTP. Ahmadini and Ahmad [17] proposed the different MFs for solving the intuitionistic fuzzy multi-objective linear programming problem. IFS contemplate both the degree of MF and non-MF, but it cannot deal with reality's inherent indeterminacy. To tackle these problems, Smarandache [18] introduced a theory of the neutrosophic set (NS), which is the degree of indeterminacy as well as the degree of truth MF and falsity MF while making decisions. Das and Roy [19] developed novel method named computational algorithm for handling the multi-objective non-linear minimization programming problem in the neutrosophic environment. Risk Allah et al.[20] proposed the neutrosophic compromise programming approach to solve the MO transportation problem under neutrosophic environment and it is verified by applying the TOPSIS technique to measure the ranking degree. Broumi and Smarandaache [21] presented innovative approaches for harmonic, geometrical, and arithmetic means for interval neutrosophic sets. Khalifa et al.[22] proposed the approach for optimality conditions to the interval valued neutrosophic TP and it is solved by Weighting Tchebycheff method. Saini et.al [23] introduced a novel approach namely minimum row column method for interval-valued trapezoidal neutrosophic transportation problem. Khalil et al. [24] discussed on the aspirations levels for interval-valued true, interval-valued falsity, and interval-valued indeterminacy, which are dependent only on the algebra of interval neutrosophic sets and confluence criteria.

The contributions of this paper are as follows:

We proposed interactive left-width method to solve the interval valued neutrosophic BOAP (IVNBOAP). The IVNBOAP is first reduced to a BOIAP using the score function and it is reduced to deterministic bi-objective assignment problem using the left-width attributes on each objective function. Then, construct the multi-objective problem by splitting each objective function. The reduced multi-objective problem cannot be solved explicitly. Also, the managers are always keen on minimizing the cost and time of AP. The global weighted sum method (GWSM) is used to transform the deterministic multi-objective AP into the single-objective AP. Using the Lingo 18.0 software, the reduced problem is solved to obtain the optimal compromise solution of the IVNBOIAP.

The construction of this paper is as follows: In Section 2, basic concepts and preliminaries are presented. Section 3 describes the problem formulation of IVNBOAP and Section 4 briefly proposed the interactive left-width method. Section 5 illustrates the proposed method implementation using the numerical examples and its computational results. In Section 6, the results and discussion part have been included and Section 7 discusses sensitivity analysis and finally the conclusion and future scope of this paper.

2. Preliminaries

The fundamental concepts of arithmetic operations, partial ordering of closed bounded intervals, interval optimal solutions, and optimal compromise solutions are found in [25].

Definition 2.1[26] An interval number is a number whose precise value is unknown, but the range in which it lies is known. An interval number with lower and upper boundaries as $A=[a^L, a^U]$, where $a^L \leq a^U$. The mid and width of the interval are similarly shown as $A=<a^m, a^w>=\{a : a^L - a^U \leq a \leq a^L + a^U, a \in R\}$, where $a^m = \frac{(a^L + a^U)}{2}$ and $a^w = (a^U - a^L)$ respectively.

Definition 2.2 [26] The order relation $\leq_{LU}$ between A $=[a^L, a^U]$ and B $=[b^L, b^U]$.

$A \leq_{LU} B$ iff $a_L \leq b_L$ and $a_U \leq b_U$,

$A <_{LU} B$ iff $A \leq_{LU} B$ and $A \neq B$.

This order relation $\leq_{LU}$ represents the decision maker's (DMs) preference for the alternative with lower minimum and maximum cost, that is, if $A \leq_{LU} B$, then A is preferred to B.

Definition 2.3 [26] The order relation $\leq_{LU}$ between A $=[a^m, a^w]$ and B $=[b^m, b^w]$.

$A \leq_{mw} B$ iff $a_m \leq b_m$ and $a_w \leq b_w$,

$A <_{mw} B$ iff $A \leq_{mw} B$ and $A \neq B$.

This order relation $\leq mw$ represents the DMs preference for the alternative with lower minimum and maximum cost, that is, if $A \leq mw\ B$, then A is preferred to B. To compare interval numbers, the total of each element in the interval number is utilised as a scale. The total of all the components of the interval number that equals zero is the zero interval.

Definition 2.4 (Neutrosophic set [27]) Let X be a universe. A neutrosophic set F over X is defined by $\tilde{\mathrm{N}}^N = \left\{\left\langle x, P^N(x), Q^N(x), R^N(x)\right\rangle : x \in X\right\}$ where $P^N, Q^N, R^N : X \to \left]0^-, 3^+\right[$ are called the truth, indeterminacy and falsity MF of the element $x \in X$ to the set $\bar{D}^N$ with $0^- \leq P^N(x) + Q^N(x) + R^N(x) \leq 3^+$.

Definition 2.6 (Interval-valued neutrosophic set [21]). Let X be a nonempty set. Then an interval valued neutrosophic (IVN) set of X is defined as:

$\tilde{\mathrm{N}}^{IVN} = \left\{\left\langle x, [P_L^{IVN}(x), P_U^{IVN}(x)], [Q_L^{IVN}(x), Q_U^{IVN}(x)], [R_L^{IVN}(x), R_U^{IVN}(x)]\right\rangle : x \in X\right\}$, where

$\left([P_L^N(x), P_U^N(x)], [Q_L^N(x), Q_U^N(x)], [R_L^N(x), R_U^N(x)]\right) \in [0,1]$.

The neutrosophic numbers, trapezoidal neutrosophic numbers and its arithmetic operation are referred in [28].

Definition 2.7 Let $\tilde{f}^{IVN}$ be the TrNNs and it can be evaluated using the score function and accuracy function as follows:

i. Score function $SC\left(\tilde{f}^{IVN}\right)=\left(\frac{1}{16}\right)\left[r+s+t+u\right]*\left[P^{IVN}+(1-Q^{IVN})+(1-R^{IVN})\right]$

ii. Accuracy function $AC\left(\tilde{f}^{IVN}\right)=\left(\frac{1}{16}\right)\left[r+s+t+u\right]*\left[\lambda_{\tilde{p}^N}+(1-\delta_{\tilde{p}^N})+(1+\sigma_{\tilde{p}^N})\right]$

3. Description and Problem formulation

This section defines the model assumption, indices, formulation of interval valued neutrosophic bi-objective assignment problem.

3.1 Mathematical Model of Interval valued Neutrosophic Bi-Objective Assignment Problem

We consider n skilled workers in agencies and the n companies want the workers to process their jobs. Each worker has to be associated with one and only one company. A penalty $\tilde{c}_{ij}^{IVN}=\left(c_{ij}^1,c_{ij}^2,c_{ij}^3,c_{ij}^4;[P_L^{IVN},P_U^{IVN}],[Q_L^{IVN},Q_U^{IVN}],[R_L^{IVN},R_U^{IVN}]\right)$ is the cost of transport and $\tilde{t}_{ij}^{N}=\left(t_{ij}^1,t_{ij}^2,t_{ij}^3,t_{ij}^4;[P_L^{IVN},P_U^{IVN}],[Q_L^{IVN},Q_U^{IVN}],[R_L^{IVN},R_U^{IVN}]\right)$ is the total time to reach the companies, which is incurred when companies j (j =1,2,...,n) is processed by the workers i (i =1,2,...,n) respectively. Let $\tilde{x}_{ij}^{N}=\left(x_{ij}^{1},x_{ij}^{2},x_{ij}^{3},x_{ij}^{4};[P_L^{IVN},P_U^{IVN}],[Q_L^{IVN},Q_U^{IVN}],[R_L^{IVN},R_U^{IVN}]\right)$ denote the assignment of j^{th} company to i^{th} worker. Our aim is to determine the worker-to-company assignment at a minimum assignment cost and time to the companies.

Now, the mathematical model of the above IVNBOAP is given as detailed below.

(A) $$Minimize\ \tilde{Z}_1^{IVN}(x)=\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{c}_{ij}^{IVN}\tilde{x}_{ij}^{IVN}, \quad (1)$$

$$Minimize\ \tilde{Z}_2^{IVN}(x)=\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{t}_{ij}^{IVN}\tilde{x}_{ij}^{IVN}, \quad (2)$$

subject to the constraints

$$\sum_{j=1}^{n}\tilde{x}_{ij}^{IVN}=1^{IVN}, i=1,2,...,n, \quad (3)$$

$$\sum_{i=1}^{n}\tilde{x}_{ij}^{IVN}=1^{IVN}, j=1,2,...,n, \quad (4)$$

$$\tilde{x}_{ij}^{IVN}=0^{IVN}\ or\ 1^{IVN}\ \text{for all i and j.} \quad (5)$$

Using score function (Definition 2.7) the problem (A) is reduced to bi-objective interval AP (B). Now, the mathematical model of the BOIAP is given as detailed below.

(B) $$Minimize[Z_1^L,Z_1^U]=\sum_{i=1}^{n}\sum_{j=1}^{n}\left[c_{ij}^L,c_{ij}^U\right]x_{ij} \quad (6)$$

$$Minimize[Z_2^L, Z_2^U] = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[t_{ij}^L, t_{ij}^U\right]x_{ij} \quad (7)$$

subject to the constraints

$$\sum_{j=1}^{n} x_{ij} = 1 \text{ for } i = 1, 2, \ldots n \quad (8)$$

$$\sum_{i=1}^{n} x_{ij} = 1 \text{ for } j = 1, 2, \ldots n \quad (9)$$

x_{ij} = 0 or 1 for all i and j. (10)

Ishibuchi and Tanaka[26] state that the expected value and interval uncertainty can be attributed to an interval's midpoint and width. Since the objective function (6) and (7) of Problem (B) is the cost and time function which is to be minimized simultaneously and our aim is to obtain optimal compromise solution with minimum ambiguity. We can express the problem (B) in terms of expected cost and time using definition (2.1). Since any two of the four characteristics of an interval—left limit, right limit, mid-value, and width—can be used to represent it. Finally, the objective function of BOIAP (6) and (7) can be reduced to a left and width objective value problem (M) by employing left and width attributes.

$$\text{(M)} \quad Minimize < Z_1^L, Z_1^w > = \sum_{i=1}^{n}\sum_{j=1}^{n} < c_{ij}^L, c_{ij}^w > x_{ij} \quad (11)$$

$$Minimize < Z_2^L, Z_2^w > = \sum_{i=1}^{n}\sum_{j=1}^{n} < t_{ij}^L, t_{ij}^w > x_{ij} \quad (12)$$

subject to the constraints (8) to (10).

Construct the multi objective problem (N) by splitting the left and width of each objective function (11) and (12).

$$\text{(N)} \quad Minimize \;\; Z_1{}^L = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}^m x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}^w x_{ij} \quad (13)$$

$$Minimize \;\; Z_1{}^w = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}^w x_{ij} \quad (14)$$

$$Minimize \, Z_2{}^L = \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}^m x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}^w x_{ij} \quad (15)$$

$$Minimize \, Z_2{}^w = \sum_{i=1}^{n}\sum_{j=1}^{n} t_{ij}^w x_{ij} \quad (16)$$

subject to the constraints (8) to (10).

The width of the cost coefficient of Z_1, $c_{ij}^w = \left(\dfrac{c_{ij}^U - c_{ij}^L}{2}\right)$,

The mid-point of the cost coefficient of Z_1, $c_{ij}^m = \left(\dfrac{c_{ij}^U + c_{ij}^L}{2}\right)$,

The width of the cost coefficient of Z_2, $t_{ij}^w = \left(\dfrac{t_{ij}^U - t_{ij}^L}{2}\right)$, The mid-point of the cost coefficient of Z_2, $t_{ij}^{m} = \left(\dfrac{t_{ij}^{U} + t_{ij}^{L}}{2} \right)$.

4. Interactive Left-Width Method (ILWM)

Step 1: Construct the problem (B) from the problem (A) using the Score function.

Step 2: Using left and width attributes, the objective function of (B) can be reduced into a left and width value problem (M).

Step 3: Construct the multi objective problem (N) by splitting the left and width objective value problem (M).

Step 4: Reduce the problem (N) into single objective problem (G) using global weighted sum method [29].

Step 5: Using step 4, the optimal compromise solution for (G) is obtained. Also, the optimal compromise solution for the problem (A) is obtained from each x_{ij} through proposed method.

4.1 Working Methodology

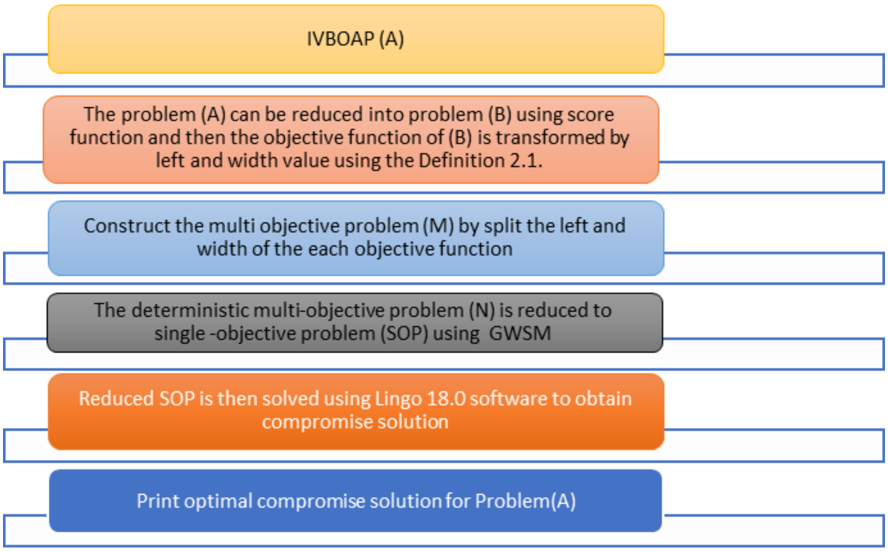

Figure 1: Working methodology of BOIAP

5. Application Example

In this section, two application examples are provided to illustrate our proposed method.

Example 5.1 A labour agency must arrange the distribution of three distinct skilled workers to three distinct companies in three different locations. Consider that there are two objectives to be considered: (i) Determine the distribution that reduces the overall cost of transferring workers to companies. (ii) Reduce the overall travel time (in hours) to the companies. We typically can't get this information precisely because the allocation schedule has been prepared in advance. The typical method for obtaining interval data for this condition is to rate the experience. Consider the following IVNBOAP, which is shown in the Table 1.

Table 1: The bi- objective interval valued neutrosophic AP.

		D1	D2	D3
c_{ij}/ t_{ij}	S1	$[\tilde{c}_{11}]^{IVN}$ $[\tilde{t}_{11}]^{IVN}$	$[\tilde{c}_{12}]^{IVN}$ $[\tilde{t}_{12}]^{IVN}$	$[\tilde{c}_{13}]^{IVN}$ $[\tilde{t}_{13}]^{IVN}$
	S2	$[\tilde{c}_{21}]^{IVN}$ $[\tilde{t}_{21}]^{IVN}$	$[\tilde{c}_{22}]^{IVN}$ $[\tilde{t}_{22}]^{IVN}$	$[\tilde{c}_{23}]^{IVN}$ $[\tilde{t}_{23}]^{IVN}$
	S3	$[\tilde{c}_{31}]^{IVN}$ $[\tilde{t}_{31}]^{IVN}$	$[\tilde{c}_{33}]^{IVN}$ $[\tilde{t}_{32}]^{IVN}$	$[\tilde{c}_{33}]^{IVN}$ $[\tilde{t}_{33}]^{IVN}$

$[\tilde{c}_{11}]^{IVN}$= ((10, 11, 12, 13);[0.1,0.7],[0.8,0.8],[0.8,0.9]); $[\tilde{t}_{11}]^{IVN}$ = ((18, 27, 29, 30);[0.1,0.5],[0.8,0.8],[0.9,0.9])

$[\tilde{c}_{12}]^{IVN}$ = ((28,29, 31, 38);[0.1,0.6],[0.7,0.7],[0.8,0.8]); $[\tilde{t}_{12}]^{IVN}$ = ((10, 12, 25, 26);[0.1,0.6],[0.8,0.9],[0.9,0.9])

$[\tilde{c}_{13}]^{IVN}$ = ((23, 25, 31, 38); [0.1,0.6], [0.7,0.7],[0.8,0.8]); $[\tilde{t}_{13}]^{IVN}$= ((10, 11, 12, 13);[0.1,0.9], [0.7,0.7],[0.9,0.6])

$[\tilde{c}_{21}]^{IVN}$ =((14, 17, 21, 28);[0.2,0.9], [0.2,0.3],[0.6,0.6]); $[\tilde{t}_{21}]^{IVN}$= ((23, 25, 31, 38);[0.1,0.5], [0.7,0.8],[0.8,0.9])

$[\tilde{c}_{22}]^{IVN}$ =((18, 19, 21, 22);[0.1,0.9], [0.8,0.8],[0.9,0.9]); $[\tilde{t}_{22}]^{IVN}$= ((14, 17, 21, 28);[0.2,0.8], [0.2,0.2],[0.6,0.6])

$[\tilde{c}_{23}]^{IVN}$ =((18,27, 29, 30);[0.1,0.5], [0.8,0.8],[0.9,0.9]); $[\tilde{t}_{23}]^{IVN}$= ((15, 17, 21, 28);[0.2,0.9], [0.1,0.2],[0.4,0.6])

$[\tilde{c}_{31}]^{IVN}$ =((14, 17, 21, 28);[0.2,0.9], [0.2,0.2],[0.6,0.6]); $[\tilde{t}_{31}]^{IVN}$ =((23, 25, 31, 38);[0.1,0.6], [0.7,0.7],[0.8,0.8])

$[\tilde{c}_{32}]^{IVN}$ =((18, 27, 29, 30);[0.1,0.5], [0.8,0.8],[0.9,0.9]); $[\tilde{t}_{32}]^{IVN}$= ((23, 25, 31, 38);[0.1,0.5], [0.8,0.8],[0.9,0.9])

$[\tilde{c}_{33}]^{IVN}$ =((28, 29, 31, 38);[0.1,0.6], [0.7,0.8],[0.8,0.9]); $[\tilde{t}_{33}]^{IVN}$= ((10, 11, 12, 13);[0.1,0.5], [0.8,0.9],[0.8,0.9])

Using Step 1, the problem (A) is reduced to problem (B) using the score function (definition 2.7) as shown in Table 2.

Table 2: The bi- objective interval assignment problem.

		Labour Agencies		
		L_1	L_2	L_3
Workers	W_1	[1,3] [3,5]	[5,9] [2,4]	[4,8] [1,5]
	W_2	[7,10] [4,6]	[2,6] [7,10]	[3,5] [9,11]
	W_3	[7,11] [4,8]	[3,5] [3,6]	[5,7] [1,2]

Using Step 2, construct the problem (M) from the problem (B) by using the definition (2.1) as shown in Table 3.

Table 3: The bi- objective left-width assignment problem(M).

		Labour Agencies		
		L_1	L_2	L_3
Workers	W_1	<1,1> <3,1>	<5,2> <2,1>	<4,2> <1,2>
	W_2	<7,1.5> <4,1>	<2,2> <7,1.5>	<3,1> <9,1>
	W_3	<7,2> <4,2>	<3,1> <3,1.5>	<5,1> <1,0.5>

By Step 3, split the problem (M) into four objectives (z_1^L, z_1^W, z_2^L, z_2^W) by left and width objective function, which is shown in below Table 4.

Table 4: Multi- objective assignment problem(N).

		Labour Agencies											
		Problem (z_1^L)			Problem (z_1^W)			Problem(z_2^L)			Problem (z_2^W)		
		L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
Workers	W_1	1	5	4	1	2	2	3	2	1	1	1	2
	W_2	7	2	3	1.5	2	1	4	7	9	1	1.5	1
	W_3	7	3	5	2	1	1	4	3	1	2	1.5	0.5

By Step 4, the problem (M) is reduced into single objective problem (SOP) using global weighted sum method as follows. In problem (M), solve each objective function individually with the constraints (8-10) using the Hungarian algorithm. Optimal solution for (z_1^L) = 7, $x_{11}=x_{23}=x_{32}=1$, (z_1^W)=3, $x_{11}=x_{23}=x_{32}=1$, (z_2^L) =7, $x_{12}=x_{21}=x_{33}=1$, and (z_2^W)=2.5, $x_{11}=x_{23}=x_{32}=1$. Then, create the pay-off matrix is as shown in Table 5.

Table 5: Pay-off matrix

	z_1^L	z_1^W	z_2^L	z_2^W
x1	**7**	3	15	3.5
x2	7	**3**	15	3.5
x3	17	4.5	**7**	2.5
x4	17	4.5	7	**2.5**

We find the lower and upper bound of each objective function that is L1=7, L2=3, L3=7, L4=2.5, U1=17, U2=4.5, U3=15, U4=3.5. Formulate the deterministic model with the weights 0.25 to each objective,

(G)Minimize η;

subject to the constraints (9) to (11), $\eta \geq 0$;.

$$\eta=\left\{0.25\left(\frac{Z_1^L-7}{17-7}\right)^2+0.25\left(\frac{Z_1^w-3}{4.5-3}\right)^2+0.25\left(\left[\frac{Z_2^L-7}{15-7}\right]\right)^2+0.25\left(\frac{Z_2^w-2.5}{3.5-2.5}\right)^2\right\}^{\frac{1}{2}};$$

Then, using Step 5, Lingo 18.0 software is employed to solve the problem (G) to obtain optimal allocation is $x_{11}=x_{22}=x_{33}=1$. Replace the optimal allocation of the problem (G) to the problem (B) is Z=([8,16],[11,17]) and for problem (A) is $\tilde{Z}^{IVN}$ ={((56,59,64,73);[0.7,0.9],[0.7,0.8],[0.8,0.9]), ((42,55,62,71);[0.8,0.9], [0.2,0.2],[0.6,0.6])}.

Example 5.2 The bi- objective interval- valued Neutrosophic AP model is considered in order to confirm the method's efficacy: Three separate skilled workers must be allocated among three various branches of businesses in four different locations, according to an automobile manufacturing corporation. Consider that there are two goals to consider: (i) Identify the distribution that minimizes the overall cost of hiring new personnel. (ii) Shorten the distance travelled (in hours) between the companies. Typically, the allocation plan has been created in advance, thus we are unable to obtain this information precisely. The standard method is to rate the experience to gather interval data for this circumstance. Consider the following bi-objective interval valued neutrosophic assignment problem is shown in Table 6.

Table 6: The bi- objective interval valued neutrosophic AP.

		D1	D2	D3	D4
c_{ij}/ t_{ij}	S1	$[\tilde{c}_{11}]^{IVN}$ $[\tilde{t}_{11}]^{IVN}$	$[\tilde{c}_{12}]^{IVN}$ $[\tilde{t}_{12}]^{IVN}$	$[\tilde{c}_{13}]^{IVN}$ $[\tilde{t}_{13}]^{IVN}$	$[\tilde{c}_{14}]^{IVN}$ $[\tilde{t}_{14}]^{IVN}$
	S2	$[\tilde{c}_{21}]^{IVN}$ $[\tilde{t}_{21}]^{IVN}$	$[\tilde{c}_{22}]^{IVN}$ $[\tilde{t}_{22}]^{IVN}$	$[\tilde{c}_{23}]^{IVN}$ $[\tilde{t}_{23}]^{IVN}$	$[\tilde{c}_{24}]^{IVN}$ $[\tilde{t}_{24}]^{IVN}$
	S3	$[\tilde{c}_{31}]^{IVN}$ $[\tilde{t}_{31}]^{IVN}$	$[\tilde{c}_{33}]^{IVN}$ $[\tilde{t}_{32}]^{IVN}$	$[\tilde{c}_{33}]^{IVN}$ $[\tilde{t}_{33}]^{IVN}$	$[\tilde{c}_{34}]^{IVN}$ $[\tilde{t}_{34}]^{IVN}$

$[\tilde{c}_{11}]$= ((14, 17, 23, 28);[0.3,0.8], [0.2,0.3],[0.1,0.2]); $[\tilde{t}_{11}]$= ((14, 17, 21, 28);[0.4,0.9], [0.1,0.3],[0.5,0.5])

$[\tilde{c}_{12}]$= ((26,27, 30, 33);[0.4,0.9], [0.2,0.3],[0.2,0.4]); $[\tilde{t}_{12}]$= ((26, 27, 30, 33);[0.6,0.9], [0.2,0.3],[0.2,0.3])

$[\tilde{c}_{13}]$= ((49, 50, 55, 57);[0.5,0.9], [0.4,0.5],[0.5,0.6]); $[\tilde{t}_{13}]$= ((49, 50, 55, 57);[0.5,0.9], [0.4,0.5],[0.5,0.6])

$[\tilde{c}_{14}]$=((49, 52, 55, 57);[0.4,0.9], [0.4,0.5],[0.4,0.5]); $[\tilde{t}_{14}]$= ((26, 27, 30, 33);[0.6,0.9], [0.2,0.2],[0.2,0.2])

$[\tilde{c}_{21}]$=((48, 49, 50, 51);[0.1,0.9], [0.5,0.5],[0.4,0.4]); $[\tilde{t}_{21}]$= ((17, 19, 23, 28);[0.2,0.8], [0.3,0.3],[0.2,0.2])

$[\tilde{c}_{22}]$=((53, 56, 57, 58);[0.1,0.9], [0.5,0.6],[0.9,0.9]); $[\tilde{t}_{22}]$= ((51, 56, 57, 58);[0.1,0.9], [0.5,0.6],[0.6,0.9])

$[\tilde{c}_{23}]$=((14,17, 21, 28);[0.4,0.9], [0.1,0.3],[0.5,0.5]); $[\tilde{t}_{23}]$= ((26, 27, 30, 33);[0.6,0.9], [0.2,0.2],[0.2,0.2])

$[\tilde{c}_{24}]$=((60, 61, 65, 69);[0.3,0.7], [0.5,0.7],[0.7,0.8]); $[\tilde{t}_{24}]$= ((60, 61, 65, 69);[0.4,0.6], [0.5,0.7],[0.6,0.7])

$[\tilde{c}_{31}]$=((49, 52, 56, 58);[0.4,0.9], [0.4,0.5],[0.5,0.5]); $[\tilde{t}_{31}]$= ((30, 34, 38, 45);[0.1,0.9], [0.6,0.6],[0.5,0.5])

$[\tilde{c}_{32}]$=((28, 31, 35, 38);[0.1,0.9], [0.6,0.6],[0.3,0.3]); $[\tilde{t}_{32}]$= ((49, 50, 52, 53);[0.5,0.9], [0.5,0.5],[0.4,0.4])

$[\tilde{c}_{33}]$=((48, 49, 50, 51);[0.5,0.9], [0.5,0.5],[0.4,0.4]); $[\tilde{t}_{33}]$= ((59, 65, 80, 83);[0.5,0.6], [0.7,0.7],[0.4,0.4])

$[\tilde{c}_{34}]$=((49, 52, 56, 58);[0.2,0.6], [0.6,0.6],[0.5,0.5]); $[\tilde{t}_{34}]$= ((72, 82, 83, 84);[0.4,0.6], [0.6,0.7],[0.4,0.5])

By Step 1, using the score function (definition 2.7) the problem (A) is reduced to problem (B) as shown in Table 7.

Table 7: The bi- objective interval unbalanced assignment problem.

c_{ij}/ t_{ij}		D1	D2	D3	D4
	S1	[10,12] [9,11]	[15,16] [16,17]	[21,24] [21,24]	[21,25] [16,18]
	S2	[15,25] [9,13]	[10,20] [14,19]	[9,11] [16,18]	[18,19] [19,20]
	S3	[20,26] [9,17]	[10,17] [20,26]	[20,25] [25,27]	[15,20] [28,29]

Using Step 2, construct the problem (N) by using the equations (6-17) which is shown in Table 8.

Table 8: The bi- objective left-width unbalanced assignment problem.

c_{ij}/ t_{ij}		D1	D2	D3	D4
	S1	<10,1> <9,1>	<15,0.5> <16,0.5>	<21,1.5> <21,1.5>	<21,2> <16,1>
	S2	<15,5> <9,2>	<10,5> <14,2.5>	<9,1> <16,1>	<18,0.5> <19,0.5>
	S3	<20,3> <9,4>	<10,3.5> <20,3>	<20,2.5> <25,1>	<15,2.5> <28,0.5>

By Step 3, split the problem (N) into four objective using left and width values of the function. Table 9 and Table 10 shows that the multi- objective unbalanced assignment problem (MOUBAP) for cost and time.

Table 9: The multi- objective unbalanced assignment problem for cost.

		Labour Agencies (z_1^L)				**Labour Agencies (z_1^W)**			
		D1	D2	D3	D4	D1	D2	D3	D4
Workers	S1	10	15	21	21	1	0.5	1.5	2
	S2	15	10	9	18	5	5	1	0.5
	S3	20	10	20	15	3	3.5	2.5	2.5

Table 10: The multi- objective unbalanced assignment problem for time.

		Labour Agencies (z_2^L)				**Labour Agencies (z_2^W)**			
		D1	D2	D3	D4	D1	D2	D3	D4
Workers	S1	9	16	21	16	1	0.5	1.5	1
	S2	9	14	16	19	2	2.5	1	0.5
	S3	9	20	25	28	4	3	1	0.5

Now, using Step 4, reduce the MOUBAP into SOP using global weighted sum method. Then, formulate the deterministic model with the weights 0.25 to each objective function. Using Step 5, obtain the optimal compromise solution for the problem (B) is $x_{11}=x_{23}=x_{34}=x_{42}=1$, Z=([34,43],[53,58]) and for the problem (A) is $\tilde{Z}^{IVN}$ = {((77, 86, 100, 114);[0.4,0.9], [0.1,0.3],[0.1,0.2]), ((112, 126, 134, 143);[0.6,0.9], [0.1,0.2],[0.2,0.2])}.

6. Result and Discussion

The numerical examples are used to investigate the efficacy of the proposed interactive left-width method to obtain the optimal compromise solution. Table 11 and Table 12 displays the comparison between the optimal compromise solution for the problem (B) with different existing solution methods. Table 11 demonstrates that optimal compromise solution for example 1, which is obtained by our proposed method is same to Global criteria method (GCM) [30] and obtain minimum value to the Fuzzy programming approach [31], Weighted sum method [32]. Table 12 demonstrates that optimal compromise solution for example 2, which is obtained by our proposed method is same to Global criteria method and obtain minimum value to the Fuzzy programming approach, Weighted sum method. To show the effectiveness, the same is plotted in the Figure 2 and Figure 3. The optimal compromise solution for our proposed approach is minimum by taking average to the interval. Overall, the proposed strategy is better suited to problems involving multi-criteria in structures.

Table 11 Optimal compromise solution for different approaches-Example 1

Approaches	Allocations	Optimal compromise solution
Fuzzy programming approach[31]	$x_{11}=x_{23}=x_{32}=1$	Z=([7,13],[15,22])
Weighted sum method[32]	$x_{11}=x_{23}=x_{32}=1$	Z=([7,13],[15,22])
Global criteria method[30]	$x_{11}=x_{22}=x_{33}=1$	Z=([8,16],[11,17])
Proposed interactive left-width method	$x_{11}=x_{22}=x_{33}=1$	Z=([8,16],[11,17])

Table 12 Optimal compromise solution for different approaches-Example 2

Approaches	Allocations	Optimal compromise solution
Fuzzy programming approach	$x_{14}=x_{23}=x_{32}=x_{41}=1$	Z=[(40,53);(52,62)]
Weighted sum method	$x_{14}=x_{23}=x_{32}=x_{41}=1$	Z=[(40,53);(52,62)]
Global criteria method	$x_{11}=x_{23}=x_{34}=x_{42}=1$	Z=([34,43],[53,58])
Proposed interactive left-width method	$x_{11}=x_{23}=x_{34}=x_{42}=1$	Z=([34,43],[53,58])

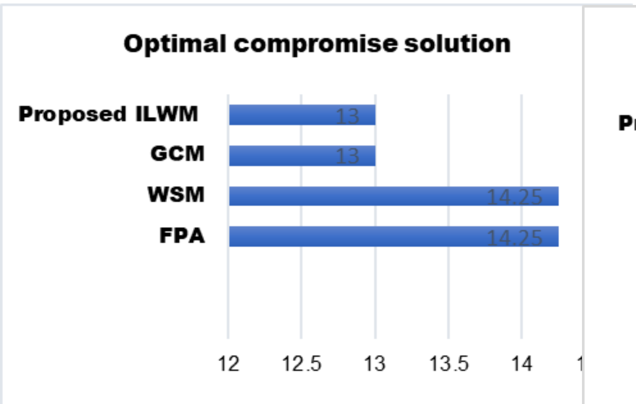

Figure 2: Comparison for Example 1

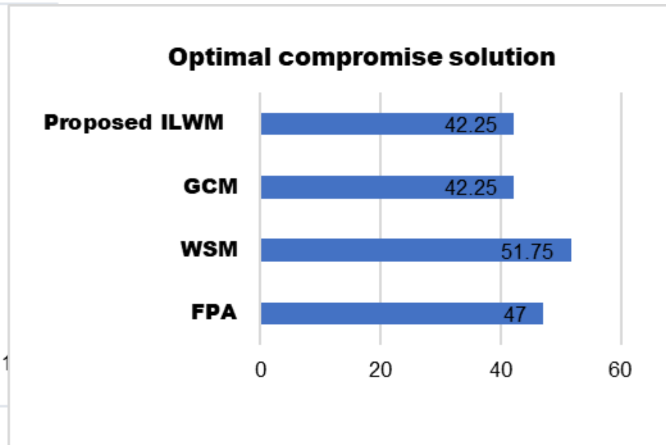

Figure 3: Comparison for Example 2

7. Sensitivity analysis

In this section, sensitivity analysis (SA) is performed for the optimality in terms of cost coefficients for the problem (B). First, we perform the SA of first objective problem having the interval cost $\left[c_{ij}^{L}, c_{ij}^{U}\right]$ and then for the second objective having the interval time $\left[t_{ij}^{L}, t_{ij}^{U}\right]$. We split interval cost $\left[c_{ij}^{L}, c_{ij}^{U}\right]$ and time $\left[t_{ij}^{L}, t_{ij}^{U}\right]$ as lower bound IAP c_{ij}^{L} , t_{ij}^{L} and upper bound IAP c_{ij}^{U} , t_{ij}^{U} . Analyse the sensitivity of (i,j)th cost of upper and the lower bound of interval for the problem (B). Using GWSM the optimal compromise solution obtained for problem (B) is $x_{11}=x_{22}=x_{33}=1$. Therefore, the basic cells of the given problem (B) are (1,1), (2,2) and (3,3). Now, analyse the sensitivity range of (i,j)th cost for the c_{ij}^{L} to the problem (B). Replace the (i,j)th cost value c_{ij}^{L} by $c_{ij}^{L}+\lambda$ in which the parameter λ may vary. We find the modi indices *ui* and *vj* to calculate $(c_{ij}^{L}+\lambda)-(ui+vj)\geq 0$ for all i and j. Then, we compute the minimum and maximum range of λ (i.e) $[\lambda^{*}, \lambda^{**}]$, so that the optimal basis to the problem c_{ij}^{L} is not changed. Hence, the sensitivity ranges is $[c_{ij}^{L}+\lambda^{*}, c_{ij}^{L}+\lambda^{**}]$.

Similarly, we can calculate for c_{ij}^{U} , t_{ij}^{L} and t_{ij}^{U}.

Now, we preform the SA for each cell in the c_{ij}^{L} which is a basic/ non-basic variable cell.

Case (Ia): Now, we consider the SA of the c_{ij}^{L} in the basic cell (1, 1) and compute the ranges of non-basic variables, $(c_{ij}^{L}+\lambda)-(ui+vj)\geq 0$ for all i and j.

Table 13

u_i / v_j	$v_1=1+\lambda$	$v_2=5$	$v_3=4$
$u_1=0$	$1+\lambda$	5	4
$u_2=0$	7	2	3
$u_3=0$	7	3	5

Compute the ranges of non-basic variables, $7-(0+1+\lambda)\geq 0$. Then, λ varies from -∞ to 6. Therefore, sensitivity range of c_{ij}^{L} varies from -∞ to 7..

Case (Ib): We consider the SA of the c_{11}^{U} in the basic cell (1, 1).

Table 14

u_i / v_j	$v_1=3$	$v_2=6$	$v_3=5$
$u_1=0$	$3+\lambda$	9	8
$u_2=0$	10	6	5

u_3=0	11	5	7

Compute the ranges of non-basic variables (i.e) 10 − (0 +3+λ) ≥ 0 and 11 − (0 +3+λ) ≥ 0. Then, choose the minimum range of λ that varies from -∞ to 7. Therefore, c_{11}^{U} varies from -∞ to 10. Thus, the cell (1,1) interval cost, $\left[c_{11}^{L}, c_{11}^{U}\right]$ varies from (-∞, -∞) to [7, 10].

Similarly, we can do for the second objective function. Then, the lower **δ** varies from -∞ to 1 and t_{11}^{L} varies from -∞ to 4. Then, upper **δ** varies from -∞ to 1 and t_{11}^{U} varies from -∞ to 6. Therefore, $\left[t_{ij}^{L}, t_{ij}^{U}\right]$ varies from [-∞, -∞] to [4, 6].

Next, we consider the SA of the c_{ij}^{L} in the cell (1, 2) which is a non-basic cell.

Case (IIa): We consider the SA of the lower bound TP in the cell (1, 2).

Table 15

u_i / v_j	v_1 =1	v_2 =2	v_3 =5
u_1 =0	1	5+λ	4
u_2=0	7	2	3
u_3=0	7	3	5

Then, $\boldsymbol{\lambda}_{12}$ varies from -3 to ∞. Thus, c_{12} varies from 2 to ∞.

Case (IIb): We consider the SA of the upper bound TP in the cell (1, 2).

Table 16

u_i / v_j	v_1 =3	v_2 =6	v_3 =5
u_1 =0	3	9+λ	8
u_2=0	10	6	5
u_3=0	11	5	7

Then, **λ** varies from -∞ to -3. Thus, c_{12} varies from -∞ to 6. Similarly, we can do for the second objective function. Then, lower **δ** varies from 5 to ∞ and t_{12} varies from 10 to ∞. Then, upper **δ** varies from 6 to ∞ and t_{12} varies from 10 to ∞. Therefore, $\left[t_{ij}^{L}, t_{ij}^{U}\right]$ varies from [7,10] to [∞, ∞]. Similarly, we can find the sensitivity ranges of costs in the problem (B) which is shown in Table 17 and Table 18.

Table 17 SA for First objective problem(B)

Limit for c_{ij}^L	Limit for c_{ij}^U	Limit for $\left[c_{ij}^L, c_{ij}^U\right]$
$-\infty \le c_{11} \le 7$	$-\infty \le c_{11} \le 10$	$[-\infty,-\infty] \le c_{11} \le [7,10]$
$2 \le c_{12} \le \infty$	$6 \le c_{12} \le \infty$	$[2,6] \le c_{12} \le [\infty,\infty]$
$5 \le c_{13} \le \infty$	$7 \le c_{13} \le \infty$	$[5,7] \le c_{13} \le [\infty,\infty]$
$1 \le c_{21} \le \infty$	$3 \le c_{21} \le \infty$	$[1,3] \le c_{21} \le [\infty,\infty]$
$-\infty \le c_{22} \le 3$	$-\infty \le c_{22} \le 3$	$[-\infty,-\infty] \le c_{22} \le [3,3]$
$5 \le c_{23} \le \infty$	$7 \le c_{23} \le \infty$	$[5,7] \le c_{23} \le [\infty,\infty]$
$1 \le c_{31} \le \infty$	$3 \le c_{31} \le \infty$	$[1,3] \le c_{31} \le [\infty,\infty]$
$2 \le c_{32} \le \infty$	$6 \le c_{32} \le \infty$	$[2,6] \le c_{32} \le [\infty,\infty]$
$-\infty \le c_{33} \le 3$	$-\infty \le c_{33} \le 5$	$[-\infty,-\infty] \le c_{11} \le [3,5]$

Table 18 SA for Second objective problem(B)

Limit for t_{ij}^L	Limit for t_{ij}^U	Limit for $\left[t_{ij}^L, t_{ij}^U\right]$
$-\infty \le t_{11} \le 4$	$-\infty \le t_{11} \le 6$	$[-\infty,-\infty] \le t_{11} \le [4,6]$
$7 \le t_{12} \le \infty$	$10 \le t_{12} \le \infty$	$[7,10] \le t_{12} \le [\infty,\infty]$
$1 \le t_{13} \le \infty$	$2 \le t_{13} \le \infty$	$[1,2] \le t_{13} \le [\infty,\infty]$
$3 \le t_{21} \le \infty$	$5 \le t_{21} \le \infty$	$[3,5] \le t_{21} \le [\infty,\infty]$
$-\infty \le t_{22} \le 2$	$-\infty \le t_{22} \le 4$	$[-\infty,-\infty] \le t_{22} \le [2,4]$
$1 \le t_{23} \le \infty$	$2 \le t_{23} \le \infty$	$[1,2] \le t_{23} \le [\infty,\infty]$
$3 \le t_{31} \le \infty$	$5 \le t_{31} \le \infty$	$[3,5] \le t_{31} \le [\infty,\infty]$
$7 \le t_{32} \le \infty$	$10 \le t_{32} \le \infty$	$[7,10] \le t_{32} \le [\infty,\infty]$
$-\infty \le t_{33} \le 1$	$-\infty \le t_{33} \le 5$	$[-\infty,-\infty] \le t_{33} \le [1,5]$

Table 17 and Table 18, show that the sensitivity of the interval cost parameter is used to examine how uncertainties in a parameter affect the overall uncertainty of the problem (B). This helps the DM to change the variables within models, based on information specific to a certain scenario to understand the outcome of a real-life situation.

8. Concluding remarks and future research directions

This study proposed a novel solution methodology interactive left-width technique for the interval valued neutrosophic BOAP. In this methodology the problem is first reduced to BOIAP using score function and it is reduced to a deterministic bi-objective AP using the left-width technique on each objective function. Then, each objective function of left-width problem is separated along with the constraints and multi-objective AP is constructed. Global weighted sum method is adopted to convert the multi-objective AP into SOP and then reduced problem is solved using Lingo 18.0 software to obtain the optimal compromise solution. This article demonstrates the effectiveness of the proposed interactive left-width method in problem and obtains the following improved results for the same case study: (i) illustrate the reliability and transparency of our proposed method and (ii) less assignment costs and shorter total allocation time. Applying nonlinear membership functions requires a significant amount of computational effort, which is the primary limitation of the proposed method. In future research, evolutionary computation may be used to effectively address multi-objective interval nonlinear problems in uncertain parameters. Further future research endeavors could potentially employ the solution method to address other supply chain planning problems such as inventory management, vendor selection, production distribution planning, and procurement-production-distribution planning.

Funding: There was no external support for this research.
Conflicts of Interest: There are no conflicting interests declared by the authors.

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