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Pentagonal Neutrosophic Transportation Problems with Interval Cost

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Abstract. The present paper aims to deal with a new variant of uncertain classical transportation problem namely 'Interval Pentagonal Neutrosophic Transportation Problem' (IPNTP) in which the uncertainty of source & destination parameters are described by pentagonal neutrosophic numbers while an estimated range (interval number) is used to represent uncertain cost of transportation. The objective consisting interval cost has been splitted into two equivalent crisp objectives using the concept of expected value & uncertainty of interval number. The constraints containing pentagonal neutrosophic quantities has also been converted into crisp constraints with the help of score function. The pareto optimal solution of the transformed bi-objective crisp transportation problem has been obtained using fuzzy programming approach. A numerical illustration is used to demonstrate the computational procedure of the proposed variant. Lingo 18.0 software is used to solve the problem.

Keywords: Fuzzy Set; Intuitionistic Set; Neutrosophic Set; Interval Numbers; Neutrosophic Transportation Problem; Pentagonal Neutrosophic Number

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1. **Introduction**

In classical transportation problem, the cost-coefficients of transporting a unit product from source i to destination j (c_{ij}), availability of the product at source i (a_i) and demand of destination j (b_j) parameters are priorly known certain quantities. However in today's uncertain world it is not at all astonishing if these quantities reflect some uncertainty. So if we logically introduce some impreciseness in these quantities, we may get a new variant of classical transportation problem. Usually the uncertainty in the problems can be dealt in three ways (i) fuzzy (ii) interval and (iii) stochastic. Fuzzy sets were introduced by Zadeh [2] in 1965 which is characterized by a membership function. The membership function assigns a grade of membership to each element of set. This grade only gives an idea about the possibility of the inclusion of respective element in the set but it does not reveal any information about non-inclusion of an element in the set. Later on Atanassov [3] proposed an extension of fuzzy set in which he also associated another grade of non-membership with each element in the fuzzy set. Such sets are known as intuitionistic fuzzy sets. Further in the year 1999, Smarandache [4] identified a situation of indeterminacy about inclusion of element in set. So he suggested the association of another grade of indeterminacy along with the grades of inclusion and non-inclusion. To overcome the limitation of intuitionistic fuzzy set, Smarandache [4] proposed the concept of neutrosophic sets. Alike fuzzy number, the concept of triangular and trapezoidal neutrosophic number and their deneutrosophication techniques have been developed by several authors (see [5]- [8]). Wang *et* al. [9] introduced the idea of single valued neutrosophic sets. In past few years, ample contribution of neutrosophic sets can be observed in multicriteria decision making ([10]- [22]), graph theory ([23]- [29]), optimization techniques ([30]- [33]) etc. The concept of neutrosophic sets has been extensively applied by several authors by logically introducing uncertainty in different ways in the parameters of classical transportation problem. For example, Thamaraiselvi and Santhi [34] presented a new approach for solving a classical transportation problem. They considered transportation problem in which the transportation cost, availability of product and demand were represented by trapezoidal neutrosophic numbers. Singh *et* al. [35] suggested a modified version of Thamaraiselvi and Santhi [34]. The uncertainty in cost, availability and demand parameters differently introduced by some authors depending various possibilities has been summarized in Table 1. In 2019, Chakaraborty *et* al. [46] discussed the advantages of using pentagonal neutrosophic numbers over triangular and trapezoidal neutrosophic numbers.

This paper considers a transportation problem with pentagonal neutrosophic availability and demand but interval cost of transportation. Since a membership grade to availability and demand of product can be assigned easily but in case of transportation cost, it varies uncontrollably within a specific range due to many reasons like; maintenance of carrier, disloyalty of drivers, fluctuation of fuel cost etc. To the best of our knowledge no such variant of the transportation problem has been considered in literature. So it is quiet advocable to represent the transportation cost in the form of interval numbers in a reasonable manner depending on past experience. The concepts of score function [47], expected value and uncertainty [1] has been applied to convert the developed uncertain transportation problem into an equivalent crisp problem. To demonstrate the procedure of transportation of IPNTP to crisp problem and its solution a numerical example is taken and solved using Lingo 18.0 software.

Table 1. Summary

Refrences	Interval Cost	Neutrosophic Supply & Demand
Narayanamoorthy & Anukokila [36]	✓	✗
Pramanik & Dey [37]	✗	✓
Das *et* al. [38]	✓	✗
Saini & Sangal [39]	✗	✓
Paul *et* al. [40]	✗	✓
Kumar Das [41]	✗	✓
Habiba & Quddoos, [42]	✓	✗
Habiba & Quddoos, [43]	✓	✗
Chakraborty *et* al. [44]	✗	✓
Sikkannan & Shanmugavel [45]	✗	✓
Akilbasha *et* al. [46]	✓	✗
Proposed IPNTP	✓	✓

2. Preliminaries

Definition 2.1 (**Fuzzy Set [2]**)**.** A Set $\widetilde{F}$ over X represented as $\widetilde{F}$=$\{(x, \mu(x)) : x \in X, \mu(x) \in [0, 1]\}$ is called a fuzzy set where X is the collection of points x and $\mu(x)$ is its truth membership function.

Definition 2.2 (**Intuitionistic Fuzzy Set [3]**)**.** A set $\widetilde{I}$ over X represented as $\widetilde{I}$=$\{x; \mu(x), \delta(x); x \in X,$ where $\mu(x), \delta(x) \in [0, 1]\}$ is called an intuitionistic fuzzy set where $\mu(x)$ and $\delta(x)$ are the truth and indeterminacy membership functions of x which satisfy the following relation:

$$0 \leq \mu(x) + \delta(x) \leq 1$$

Definition 2.3 (**Neutrosophic Set [4]**)**.** A set $\widetilde{N}$ over X represented as $\widetilde{N}$=$\{x; \mu(x), \delta(x), \sigma(x); x \in X,$ and $\mu(x), \delta(x), \sigma(x) \in [0, 1]\}$ is called a neutrosophic sets where $\mu(x)$, $\delta(x)$ and $\sigma(x)$ are the truth, indeterminacy and falsity membership functions of x which displays the following relation:

$$0 \leq \mu(x) + \delta(x) + \sigma(x) \leq 3$$

Definition 2.4 (**Single-Valued Neutrosophic Set [9]**)**.** A Neutrosophic set $\widetilde{N}$ in definition 2.3 is called as a single- valued neutrosophic set $\widetilde{SN}$ if x is a single-valued independent variable. $\widetilde{SN}$=$\{x; \mu(x), \delta(x), \sigma(x); x \in X, \}$ where $\mu(x)$, $\delta(x)$ and $\sigma(x)$ are the truth, indeterminacy and falsity membership functions of x respectively.

Definition 2.5 (**Single-Valued Pentagonal Neutrosophic Number [47]**)**.** A Neutrosophic Number (S), S=$\langle[(s^1, t^1, u^1, v^1, w^1); \mu], [(s^2, t^2, u^2, v^2, w^2); \delta], [(s^3, t^3, u^3, v^3, w^3); \sigma]\rangle$, where $\mu, \delta, \sigma \in [0,1]$ is called single-valued pentagonal neutrosophic number, if its truth membership function (μ), indeterminacy membership function (δ) and the falsity membership function (σ) are respective given as follows:

$$\mu(x) = \begin{cases} \mu_{l_1}(x) & s^1 \le x \le t^1 \\ \mu_{l_2}(x) & t^1 \le x \le u^1 \\ \mu & x = u^1 \\ \mu_{r_2}(x) & u^1 \le x \le v^1 \\ \mu_{r_1}(x) & v^1 \le x \le w^1 \\ 0 & otherwise \end{cases}$$

$$\delta(x) = \begin{cases} \delta_{l_1}(x) & s^2 \le x \le t^2 \\ \delta_{l_2}(x) & t^2 \le x \le u^2 \\ \delta & x = u^2 \\ \delta_{r_2}(x) & u^2 \le x \le v^2 \\ \delta_{r_1}(x) & v^2 \le x \le w^2 \\ 1 & otherwise \end{cases}$$

$$\sigma(x) = \begin{cases} \sigma_{l_1}(x) & s^3 \le x \le t^3 \\ \sigma_{l_2}(x) & t^3 \le x \le u^3 \\ \sigma & x = u^3 \\ \sigma_{r_2}(x) & u^3 \le x \le v^3 \\ \sigma_{r_1}(x) & v^3 \le x \le w^3 \\ 1 & otherwise \end{cases}$$

Definition 2.6 (Score Function [47]). Score function for any pentagonal single typed neutrosophic number $(P_1, P_2, P_3, P_4, P_5; \mu, \delta, \sigma)$ is defined as follows:

$$\widetilde{S} = \frac{1}{15}\{(P_1 + P_2 + P_3 + P_4 + P_5) \times (2 + \mu - \delta - \sigma)\}$$

where μ, δ and σ are the truth, indeterminacy and falsity membership functions.

Definition 2.7 (Interval Numbers [48]).

$$A = [a_L, a_R] = \{\ a :\ a_L \le\ a \le\ a_R, a \in \mathbb{R}\},$$

where a_L and a_R are the left-limit and right-limit of the interval A on the real line $\mathbb{R}$.

$$A = \langle a_c, a_w \rangle = \{\ a :\ a_c - a_w \le\ a \le\ a_c + a_w, a \in \mathbb{R}\},$$

where a_c and a_w are the mid-point and half-width (or simply be termed as 'width') of interval A on the real line $\mathbb{R}$, i.e.

$$a_c = \frac{a_R + a_L}{2}$$

$$a_w = \frac{a_R - a_L}{2}$$

Definition 2.8 (Ishibuchi and Tanaka's ranking for intervals [1]). Let $A = [a_L, a_R]=\langle a_c, a_w\rangle$ and $B = [b_L, b_R]=\langle b_c, b_w\rangle$ be two given intervals then the order relation $\leq_{CW}$ is defined as:

$$\begin{cases} A \leq_{CW} B \text{ iff } a_c \leq b_c, \text{ and } \ a_w \leq b_w \\ A <_{CW} B \text{ iff } A \leq_{CW} B, \text{ and } \ A \neq B \end{cases}$$

3. Mathematical Model of IPNTP

Consider a transportation problem in which the cost-coefficients are represented in the form of interval number & source and destination parameters are represented as pentagonal single typed neutrosophic numbers. The mathematical model of such IPNTP may be given as follows:

Problem-I:

$$\text{Minimize : } Z = \sum_{i=1}^{m}\sum_{j=1}^{n}[c_{L_{ij}}, c_{R_{ij}}]x_{ij} \tag{1}$$

Subject to;

$$\sum_{j=1}^{n} x_{ij} \leq {a_i}^S, \ i = 1, 2, \ldots, m \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} \geq {b_j}^S, \ j = 1, 2, \ldots, n \tag{3}$$

$$x_{ij} \geq 0, \ i = 1, 2, \ldots, m, \ j = 1, 2, \ldots, n \tag{4}$$

where,

$[c_{L_{ij}}, c_{R_{ij}}]$: interval cost of transporting one unit of product from source i to destination j,

$c_{L_{ij}}$: lowest possible cost of transporting one unit of product from source i to destination j,

$c_{R_{ij}}$: highest possible cost of transporting one unit of product from source i to destination j

${a_i}^S$: pentagonal single typed neutrosophic availability of source i,

${b_j}^S$: pentagonal single typed neutrosophic demand of destination j,

x_{ij}: quantity transported from source i to destination j

4. Equivalent crisp model of IPNTP

4.1. *Construction of crisp Objective Function*

Let us consider the interval objective function Z of the Problem-I which can be denoted as $Z = \langle z_c, z_w\rangle$, where $z_c = (\frac{c_R + c_L}{2})$ and $z_w = (\frac{c_R - c_L}{2})$ are the center and width of the interval Z respectively.

According to Ishibuchi and Tanaka [1] the center and width of an interval can be taken as the expected value and uncertainty of interval respectively. Since the objective function of Problem-I is the cost function which is to be minimized, so our interest is to obtain minimum cost with minimum uncertainty. Then the interval objective function (1) is transformed into a two crisp functions in terms of expected value and uncertainty by definition (2.8) as follows:

$$\text{Minimize } z_c = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{c_{ij}} x_{ij} \tag{5}$$

$$\text{Minimize } z_w = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{w_{ij}} x_{ij} \tag{6}$$

where, $c_c = \frac{c_R + c_L}{2}$ and $c_w = \frac{c_R - c_L}{2}$ are the center and width of the interval respectively.

4.2. *Construction of crisp Constraints*

Let us consider the constraint (2) of Problem-I where the right hand side ${a_i}^S$ representing the pentagonal single typed neutrosophic availability of product at source i. This pentagonal single typed neutrosophic number ${a_i}^S$ can be represented by a crisp value using the score function defined in definition (2.6). Thus corresponding crisp constraint may be written as follows:

$$\sum_{j=1}^{n} x_{ij} \le \widetilde{S}(a_i),\ i = 1, 2, \ldots, m \tag{7}$$

Similarly, the crisp destination constraint can also be obtained as follows:

$$\sum_{i=1}^{m} x_{ij} \ge \widetilde{S}(b_j),\ j = 1, 2, \ldots, n \tag{8}$$

Using equations (5-6) and (7-8), we can write the equivalent bi-objective crisp problem of IPNTP as follows:

Problem-II:

$$\text{Minimize } z_c = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{c_{ij}} x_{ij} \tag{9}$$

$$\text{Minimize } z_w = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{w_{ij}} x_{ij} \tag{10}$$

Subject to;

$$\sum_{j=1}^{n} x_{ij} \le \widetilde{S}(a_i),\ i = 1, 2, \ldots, m \tag{11}$$

$$\sum_{i=1}^{m} x_{ij} \ge \widetilde{S}(b_j),\ j = 1, 2, \ldots, n \tag{12}$$

$$x_{ij} \ge 0,\ i = 1, 2, \ldots, m,\ j = 1, 2, \ldots, n \tag{13}$$

5. Fuzzy Programming Technique for solving bi-objective transportation problem (Problem-II)

First we find the best L_k and worst U_k for the $k^{th}, k = c, w$ objective function, where L_k is the aspired level and U_k is the highest acceptable level for the k^{th} objective function. Thereafter we create a fuzzy linear programming problem using membership function. The stepwise procedure of fuzzy programming technique is given as follows:

Step 1: Solve the bi-objective transportation problem (Problem-II) as a single objective problem using only one objective at a time and ignoring other.

Step 2: From each solution derived in Step1 determine the values of both objective functions.

Step 3: Find the best L_k and worst U_k for both objectives corresponding to the set of solutions. Define a fuzzy membership function $\mu_k(Z_k)$ as follows:

$$\mu_k(Z_k) = \begin{cases} 1, & \text{if } Z_k \leq L_k \\ 1 - \frac{Z_k - L_k}{U_k - L_k}, & \text{if } L_k \leq Z_k \leq U_k \\ 0, & \text{if } Z_k \geq L_k \end{cases}$$

The equivalent linear programming problem for the vector minimum problem can be written as follows:

$$\text{Maximize} : \lambda,$$

$$\text{Subject to; } \lambda \leq \frac{U_k - Z_k}{U_k - L_k}$$

$$\text{Constraints; } (11 - 13)$$

$$0 \leq \lambda \leq 1$$

The above linear programming problem may further be simplified as:

Problem-III:

$$\text{Maximize} : \lambda,$$

$$\text{Subject to; } Z_k + \lambda(U_k - L_k) \leq U_k$$

$$\text{Constraints; } (11 - 13)$$

$$0 \leq \lambda \leq 1$$

Step 4: Solve Problem-III using any method and obtain the required pareto optimal solution.

6. Numerical Illustration

A company has three factories F_1, F_2 and F_3. A homogenous product is to be transported from these factories to four destinations D_1, D_2, D_3 and D_4 in such a way that the total shipment cost becomes minimum. The availability at each factories and requirement at each destinations and unit interval cost transportation cost from each factory to each destination are given in Table 2.

TABLE 2. Interval pentagonal neutrosophic transportation table

	D_1	D_2	D_3	D_4	Availability
F_1	[5,7]	[5,9]	[3,5]	[7,8]	(22,26,28,32,35; 0.7,0.3,0.4)
F_2	[8,12]	[7,10]	[4,8]	[5,6]	(30,33,36,38,40; 0.6,0.4,0.5)
F_3	[6,7]	[1,2]	[7,9]	[5,6]	(21,28,32,37,39; 0.8,0.2,0.4)
Demand	(13,16,18,21,25; 0.5,0.5,0.6)	(17,21,24,28,30; 0.8,0.2,0.4)	(24,29,32,35,37; 0.9,0.5,0.3)	(6,10,13,15,18; 0.7,0.3,0.4)	

The mathematical model of the given problem is as follows:

$$\text{Minimize}: Z = \sum_{i=1}^{3}\sum_{j=1}^{4}[c_{L_{ij}}, c_{R_{ij}}]x_{ij}$$

Subject to;

$$\sum_{j=1}^{4} x_{1j} \leq (22, 26, 28, 32, 35; 0.7, 0.3, 0.4), \ \sum_{j=1}^{4} x_{2j} \leq (30, 33, 36, 38, 40; 0.6, 0.4, 0.5),$$
$$\sum_{j=1}^{4} x_{3j} \leq (21, 28, 32, 37, 39; 0.8, 0.2, 0.4), \ \sum_{i=1}^{3} x_{i1} \geq (13, 16, 18, 21, 25; 0.5, 0.5, 0.6),$$
$$\sum_{i=1}^{3} x_{i2} \geq (17, 21, 24, 28, 30; 0.8, 0.2, 0.4), \ \sum_{i=1}^{3} x_{i3} \geq (24, 29, 32, 35, 37; 0.9, 0.5, 0.3),$$
$$\sum_{i=1}^{3} x_{i4} \geq (6, 10, 13, 15, 18; 0.7, 0.3, 0.4), \ x_{ij} \geq 0, \ i = 1, 2, 3, \ j = 1, 2, 3, 4$$

Using Problem-II the above problem can be written as follows:

$$\text{Minimize } z_c = \sum_{i=1}^{3}\sum_{j=1}^{4} c_{c_{ij}} x_{ij}, \qquad \text{Minimize } z_w = \sum_{i=1}^{3}\sum_{j=1}^{4} c_{w_{ij}} x_{ij}$$

where,

$$c_{c_{ij}} = \begin{bmatrix} 6 & 7 & 4 & 7.5 \\ 10 & 8.5 & 6 & 5.5 \\ 6.5 & 1.5 & 8 & 5.5 \end{bmatrix}, \qquad c_{w_{ij}} = \begin{bmatrix} 1 & 2 & 1 & 0.5 \\ 2 & 1.5 & 2 & 0.5 \\ 1 & 0.5 & 1 & 0.5 \end{bmatrix}$$

Subject to;

$$\sum_{j=1}^{4} x_{1j} \leq 19.06,\ \sum_{j=1}^{4} x_{2j} \leq 20.06,\ \sum_{j=1}^{4} x_{3j} \leq 23.01,\ \sum_{i=1}^{3} x_{i1} \geq 8.68,$$

$$\sum_{i=1}^{3} x_{i2} \geq 17.6,\ \sum_{i=1}^{3} x_{i3} \geq 21.96,\ \sum_{i=1}^{3} x_{i4} \geq 9.32,\ x_{ij} \geq 0,\ i = 1,2,3,\ j = 1,2,3,4$$

On solving the above problem using lingo 18.0 software, the pareto optimal solution of the problem is obtained as, $x_{11} = 3.27, x_{13} = 15.79, x_{23} = 6.17, x_{24} = 9.32, x_{31} = 5.41, x_{32} = 17.6$, $Z = [185.06, 280.19]$.

The above result shows that minimum total cost of transportation lies between 185.06 to 280.19. The optimal policy of transportation to be adopted by decision maker is given in Table (3).

Table 3. Optimal policy of transportation

Factoy		Destination	Suggested optimal policy of transportation
F_1	$\longrightarrow$	D_1	3.27 Units of product are to be transported from first factory to first destination
F_1	$\longrightarrow$	D_3	15.79 Units of product are to be transported from first factory to third destination
F_2	$\longrightarrow$	D_3	6.17 Units of product are to be transported from second factory to third destination
F_2	$\longrightarrow$	D_4	9.32 Units of product are to be transported from second factory to fourth destination
F_3	$\longrightarrow$	D_1	5.41 Units of product are to be transported from third factory to first destination
F_3	$\longrightarrow$	D_2	17.6 Units of product are to be transported from third factory to second destination

7. Advantages and Limitations of IPNTP

Every new study carry some limitations along with the advantages. Two major advantages and their corresponding limitations have been discussed in Table 4.

8. Conclusion and Future Work

In this paper, a more realistic variant of transportation problem namely IPNTP has been introduced with interval cost and pentagonal neutrosophic availability and demand parameters. Since the transportation cost greatly depends on many factors like sudden change in fuel prices, load carrying capacity of carrier, disloyalty of drivers and many more. So it becomes tedious

Table 4. Advantages and limitations

Advantages	Limitations
• Use of interval cost reduces their tedious task of assigning membership grade to every associated cost • Solution approaches work well for single objective problem as it converts into a bi-objective crisp problems	• Relatively more information needed to reduce the range of interval • Multiobjective problems increases the computational complexity of the problem because it doubles the number of objectives while converting into crisp one

for decision maker to assign grades to truth, indeterminacy and falsity membership functions for unit cost of transporting product from each source to every destination. To overcome this issue this article suggest the decision maker to represent the transportation cost in the form of interval number. But this issue is not valid in case of availability and demand because membership grade for availability and demand parameters may easily be assigned with the help of information received from sources and destinations. To the best of our knowledge no such variant of transportation problem is considered in literature previously.

An extension of the IPNTP with interval valued neutrosophic cost may be proposed in future research work.

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