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Solving Interval Transportation Problems with Additional Impurity Constraints

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ABSTRACT

A new method namely, split and bound method is proposed for finding an optimal solution to fully integer interval transportation problems with additional impurity constraints which has been developed without considering the midpoint and width of the intervals and is based on floating point method [14]. The proposed method is illustrated by means of the numerical example. Further, this method is extended to fully fuzzy transportation problems with additional impurity constraints. The proposed method provides an appropriate solution to the decision makers for taking best decision when they are handling various types of logistic problems having imprecise parameters.

Keywords: Interval transportation problem, additional impurity constraints, split and bound method, trapezoidal fuzzy number, fuzzy transportation problem,

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1. Introduction

The transportation problem (TP) is a special type of linear programming problem, which deals with shipping commodities from sources to destinations. Transportation models have wide applications in logistics and supply chain for reducing the cost. In many real life situations, the commodity does vary in some characteristics according to its source and the final commodity mixture reaching at destinations, may then be required to have known specifications. TP with additional impurity restrictions was stated by Haley [9]. Chandra et al. [4] developed a method for solving time minimizing TP with impurities. Interval transportation problem

(ITP) is a generalization of the TP in which input data are expressed as intervals instead of fixed values. This problem can arise when uncertainty exists in data problem and decision makers are more comfortable expressing it as intervals. Many researchers [1,5,10,11,12,17] have proposed fuzzy and interval programming techniques for solving them. Chanas et al. [2] developed an algorithm determining the optimal integer solution of a more general fuzzy transportation problem. Das et al. [6] introduced a method, called fuzzy technique to solve ITP by considering the right bound and the midpoint of the interval. Sengupta and Pal [16] proposed a new fuzzy oriented method to solve ITP by considering the midpoint and width of the interval in the objective function. Singh and Saxena [15] proposed a method for solving multiobjective time TP with additional impurity restrictions. A procedure for finding an optimal solution to fully interval integer TP was presented by Pandian and Natarajan [13]. Dutta et al. [7] introduced a linear fractional programming method for solving a fuzzy TP with additional restrictions in which transportation costs are intervals. Pandian and Anuradha [14] have proposed a floating point method for solving TP with additional constraints.

In this paper, we propose a new method namely, split and bound method based on the floating point method [14] for finding an optimal solution for integer transportation problems with additional impurity constraints in which the unit transportation costs, supplies, demands and additional impurity constraints are intervals. The proposed method is illustrated with the help of numerical example. Further, this method is extended to fuzzy transportation problems with additional impurity constraints in which all the parameters are trapezoidal fuzzy numbers (TFNs). The proposed method provides an appropriate solution to fully integer interval / fuzzy transportation problems which helps the decision makers to analyze economic activities and to arrive at the best managerial decisions.

2. Preliminaries

Let D denote the set of all closed bounded intervals on the real line R. That is, D = $\{[a,b], a \leq b \text{ and } a \text{ and } b \text{ are in } R\}$.

We need the following definitions of the basic arithmetic operators and partial ordering on closed bounded intervals which can be found in [8,11].

Definition 1: Let A = [a, b] and B = [c, d] be in D. Then,

(i) $A \oplus B = [a+c, b+d]$;

(ii) $A \Theta B = [a-d, b-c]$;

(iii) $kA = [ka, kb]$ if k is a positive real number;

(iv) $kA = [kb, ka]$ if k is a negative real number and

(v) $A \otimes B = [p, q]$ where p = min {ac, ad, bc, bd} and q = max {ac, ad, bc, bd}

Definition 2: Let A = [a, b] and B = [c, d] be in D. Then,

(i) $A \le B$ if $a \le c$ and $b \le d$;
(ii) $A < B$ if $a < c$ and $b < d$;
(iii) $A \ge B$ if $B \le A$, that is $a \ge c$ and $b \ge d$ and
(iv) $A = B$ if $A \le B$ and $B \le A$, that is, $a = c$ and $b = d$.

3. Fully interval transportation problem with additional impurity constraints

Consider the following fully interval transportation problem with additional impurity constraints (P):

(P) Minimize $[z_1, z_2] = \sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}] \otimes [x_{ij}, y_{ij}]$

subject to

$$\sum_{j=1}^{n} [x_{ij}, y_{ij}] = [a_i^1, a_i^2], \quad i = 1,2,...,m \tag{1}$$

$$\sum_{i=1}^{m} [x_{ij}, y_{ij}] = [b_j^1, b_j^2], \; j = 1,2,...,n \tag{2}$$

$$\sum_{i=1}^{m} [f_{ij}^{(k)}, g_{ij}^{(k)}] \otimes [x_{ij}, y_{ij}] \le [p_j^{(k1)}, p_j^{(k2)}], \; j = 1,2,...,n \,;\, k = 1,2,...,l \tag{3}$$

$$x_{ij} \ge 0, \; y_{ij} \ge 0 \; i = 1,2,...,m \text{ and } j = 1,2,...,n \tag{4}$$

where c_{ij}, d_{ij}, a_i^1, a_i^2, b_j^1, b_j^2, $p_j^{(k1)}$ and $p_j^{(k2)}$ are positive real numbers for all i and j.

A set $\{[x_{ij}, y_{ij}]$, for all i = 1,2,…,m and j = 1,2,…,n$\}$ is said to be a feasible solution of problem (P) if they satisfy the equations (1), (2), (3) and (4).

A feasible solution of problem (P) which minimizes the total shipping cost, that is, $\sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}] \otimes [x_{ij}, y_{ij}]$ is called an optimal solution to the problem (P).

We consider the following two problems as an upper bound (UB) problem and a lower bound (LB) problem of the given problem (P):

(UB) Minimize $z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} y_{ij}$

subject to

$$\sum_{j=1}^{n} y_{ij} = a_i^2, \; i = 1,2,...,m \tag{5}$$

$$\sum_{i=1}^{m} y_{ij} = b_j^2, \; j = 1,2,...,n \tag{6}$$

$$\sum_{i=1}^{m} g_{ij}^{(k)} y_{ij} \le p_j^{(k2)}, \ j=1,2,...,n; \ k=1,2,\ldots,l \tag{7}$$

$$y_{ij} \ge 0 \text{ for all i and j .} \tag{8}$$

(LB) Minimize $z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i^1, \ i=1,2,...,m \tag{9}$$

$$\sum_{i=1}^{m} x_{ij} = b_j^1, \ j=1,2,...,n \tag{10}$$

$$\sum_{i=1}^{m} f_{ij}^{(k)} x_{ij} \le p_j^{(k1)}, \ j=1,2,...,n; \ k=1,2,...,l \tag{11}$$

$$x_{ij} \ge 0 \text{ for all i and j} \tag{12}$$

Now, we prove the following theorem which finds the relation between optimal solutions of the problem (P) and its (UB) and (LB) problems and is used in the proposed method namely, split and bound method.

Theorem 1: If the set $\{y_{ij}^{\circ}$, for all i and j$\}$ is an optimal solution of the (UB) problem of the problem (P) and the set $\{x_{ij}^{\circ}$, for all i and j$\}$ is an optimal solution of the (LB) problem of the problem (P) with additional constraints $x_{ij} \le y_{ij}^{\circ}$, for all i and j , then the set of intervals $\{[x_{ij}^{\circ}, y_{ij}^{\circ}]$, for all i and j$\}$ is an optimal solution of problem (P).

Proof: Now, since $\{x_{ij}^{\circ}$, for all i and j$\}$ and $\{y_{ij}^{\circ}$, for all i and j$\}$ satisfy (5) to (12) and $x_{ij}^{\circ} \le y_{ij}^{\circ}$, for all i and j , we can conclude that the set $\{[x_{ij}^{\circ}, y_{ij}^{\circ}]$, for all i and j$\}$ is a feasible solution of (P).

Assume that the set of intervals $\{[x_{ij}^{\circ}, y_{ij}^{\circ}]$, for all i and j$\}$ is not an optimal solution to the problem (P).

Then, there exists a feasible solution $\{[x_{ij}, y_{ij}]$, for all i and j$\}$ to the problem (P) such that

$$\sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}] \otimes [x_{ij}, y_{ij}] < \sum_{i=1}^{m} \sum_{j=1}^{n} [c_{ij}, d_{ij}] \otimes [x_{ij}^{\circ}, y_{ij}^{\circ}].$$

This implies that

$$\sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}y_{ij} < \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}y_{ij}^{\circ} \text{ and } \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} < \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}^{\circ} \qquad (13)$$

Now, since $\{[x_{ij}, y_{ij}]$, for all i and j$\}$ is a feasible solution to the problem (P) and also, $x_{ij} \le y_{ij}$, i = 1,2,..,m and j = 1,2,..,n, we have that $\{x_{ij}$, for all i and j$\}$ and $\{y_{ij}$, for all i and j$\}$ are feasible solutions to the problems (UB) and (LB) respectively.

Since $\{x_{ij}^{\circ}$, for all i and j$\}$ and $\{y_{ij}^{\circ}$, for all i and j$\}$ are optimal solutions to the problems (UB) and (LB) respectively, we have

$$\sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}y_{ij}^{\circ} \le \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}y_{ij} \text{ and } \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}^{\circ} \le \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$

which contradicts the relation (13).

Therefore, the set of intervals $\{[x_{ij}^{\circ}, y_{ij}^{\circ}]$, for all i and j$\}$ is an optimal solution to the problem (P).

Hence the theorem.

Remark: The converse of the above theorem is also true.

3.1 Split and bound method:

We now propose a new method namely, split and bound method for finding an optimal solution to the problem (P).

The split and bound method proceeds as follows:

Step 1: Construct the (UB) problem of the given problem (P).

Step 2: Solve the (UB) problem by the floating point method [14]. Let $\{ y_{ij}^{\circ}$, for all i and j$\}$ be an optimal solution of the (UB) problem .

Step 3: Construct the (LB) problem of the given problem (P).

Step 4: Solve the (LB) problem with the upper bound constraints $x_{ij} \le y_{ij}^{\circ}$, for all i and j by the floating point method [14]. Let $\{x_{ij}^{\circ}$, for all i and j$\}$ be the optimal solution of the (LB) problem with $x_{ij} \le y_{ij}^{\circ}$.

Step 5: The set of intervals $\{[x_{ij}^{\circ}, y_{ij}^{\circ}]$, for all i and j$\}$ is an optimal solution to the given (P) by the Theorem 1..

Now, the split and bound method is illustrated by the following example.

Example 1: A coal manufacturing unit of the State has different types of coal pulverization units in each of the three work centers (j) situated in various parts of the State. The work centers (j) are receiving a fixed quantity of coal (i), which has three different grades. The basic goal is to determine a feasible interval transportation cost, while satisfying the extra requirement that the amount of sulphur impurity present in coal is less than a certain critical level. The following table displays the transportation cost, availabilities, the impurities, requirements and the maximum sulphur contents are in the form of intervals.

	Work centers j			Tons available	Sulphur contents
	1	2	3		
1	[4,13]	[3,12]	[2,6]	[4,5]	[2,2]
Coal i, 2	[4,13]	[6,14]	[7,15]	[5,6]	[1,2]
3	[7,10]	[4,8]	[6,12]	[6,9]	[0,0]
Tons required	[5,6]	[5,7]	[5,7]	[15,20]	
Max. Sulphur	[4,8]	[1,3]	[9,14]		

Now, the (UB) problem of the given problem (P) is given below:

	Work centers j			Tons available	Sulphur contents
	1	2	3		
1	13	12	6	5	2
Coal i, 2	13	14	15	6	2
3	10	8	12	9	0
Tons required	6	7	7	20	
Max. Sulphur	8	3	14		

Now, using floating point method [14], an optimal solution to the (UB) problem is obtained as $y^{\circ}_{13} = 5$, $y^{\circ}_{21} = 4$, $y^{\circ}_{23} = 2$, $y^{\circ}_{31} = 2$, $y^{\circ}_{32} = 7$ and $Z_2 = 188$.

Now, the (LB) problem of the given problem with the upper bound constraints is given below:

	Work centers j			Tons available	Sulphur contents
	1	2	3		
1	4	X	2	4	2
Coal i, 2	4	6	7	5	1
3	7	4	6	6	0
Tons required	5	5	5	15	
Max. Sulphur	4	1	9		

and $x_{ij} \le y^{\circ}_{ij}$, for all i = 1,2 ,…, m and j = 1,2 ,…, n.

Now, using floating point method [14], an optimal solution to the (LB) problem is obtained as $x^{\circ}_{13} = 4$, $x^{\circ}_{21} = 4$, $x^{\circ}_{23} = 1$, $x^{\circ}_{31} = 1$, $x^{\circ}_{32} = 5$ and $Z_1 = 58$.

Thus, an optimal solution to the given fully interval transportation problem with additional impurity constraints is $[x^{\circ}_{13}, y^{\circ}_{13}] = [4,5]$, $[x^{\circ}_{21}, y^{\circ}_{21}] = [4,4]$, $[x^{\circ}_{23}, y^{\circ}_{23}] = [1,2]$, $[x^{\circ}_{31}, y^{\circ}_{31}] = [1,2]$, $[x^{\circ}_{32}, y^{\circ}_{32}] = [5,7]$ and the minimum total interval transportation cost is [58, 188].

4. Fully fuzzy transportation problem with additional impurity constraints

Consider the following fully fuzzy transportation problem with additional impurity constraints (F)

(F) Minimize $\tilde{z} = \sum_{i=1}^{m} \sum_{j=1}^{n} \tilde{c}_{ij}\tilde{x}_{ij}$

subject to

$\sum_{j=1}^{n} \tilde{x}_{ij} = \tilde{a}_i$, $i = 1,2,...,m$

$\sum_{i=1}^{m} \tilde{x}_{ij} = \tilde{b}_j$, $j = 1,2,...,n$

$\sum_{i=1}^{m} \tilde{f}^{(k)}_{ij}\tilde{x}_{ij} \le \tilde{p}^{(k)}_{j}$, $j = 1,2,...,n$; $k = 1,2,...,l$

$\tilde{x}_{ijk} \ge \tilde{0}$, for all i and j

where all the unit shipping costs $\tilde{c}_{ij}$; supply quantities $\tilde{a}_i$; demand quantities $\tilde{b}_j$; impurities $\tilde{f}^{(k)}_{ij}$ and $\tilde{p}^{(k)}_{j}$ are assumed to be trapezoidal fuzzy numbers.

A trapezoidal fuzzy number (a,b,c,d) can be represented as an interval number form as follows:

$$(a,b,c,d) = [a + (b-a)\alpha, d - (d-c)\alpha];\ 0 \le \alpha \le 1 \qquad (14)$$

Using the relation (14), we can convert the problem (F) into an interval type problem, that is (P) and by using the split and bound method, we obtain an optimal interval solution to the problem (P). Again, using the relation (14), we can obtain an optimal solution to the given problem (F).

The solution procedure of obtaining an optimal solution to problem (F) using the split and bound method is illustrated by the following example.

Example 2: A company making iron has a different type of furnace in each of three works. The works must receive a fixed weight of ore which is available in three different grades. The cost of transportation of ore depends on its grade and the works to which it is sent. The problem is to find the allocation which minimizes the production cost while satisfying the extra requirement that the amount of phosphorus is less than a certain critical level. The following table displays the cost of transportation, availabilities, the impurities, requirements and the maximum phosphorus contents are in the form of fuzzy numbers.

	Works j			Tons available	Phosphorus contents
	1	2	3		
1	(1,2,4,7)	(0,1,3,6)	(0,1,2,3)	(1,2,4,5)	(0,1,2,3)
Ore i, 2	(1,2,4,7)	(2,3,6,7)	(3,5,7,10)	(2,3,5,6)	(0,1,1,2)
3	(3,5,7,10)	(1,2,4,7)	(2,3,6,7)	(3,4,6,7)	(0,0,0,0)
Tons required	(2,3,5,6)	(2,3,5,6)	(2,3,5,6)		
Max. Phosphorus	(1,2,9,10)	(0,1,1,2)	(4,7,14,17)		

Now, the fully interval transportation problem with additional impurity constraints to the above problem is given below:

	Works j			Tons available	Phosphorus contents
	1	2	3		
1	$[1+\alpha,7-3\alpha]$	$[0+\alpha,6-3\alpha]$	$[0+\alpha,3-\alpha]$	$[1+\alpha,5-\alpha]$	$[0+\alpha,3-\alpha]$
Ore i, 2	$[1+\alpha,7-3\alpha]$	$[2+\alpha,7-\alpha]$	$[3+2\alpha,10-3\alpha]$	$[2+\alpha,6-\alpha]$	$[0+\alpha,2-\alpha]$
3	$[3+2\alpha,10-3\alpha]$	$[1+\alpha,7-3\alpha]$	$[2+\alpha,7-\alpha]$	$[3+\alpha,7-\alpha]$	$[0+0\alpha,0-0\alpha]$
Tons required	$[2+\alpha,6-\alpha]$	$[2+\alpha,6-\alpha]$	$[2+\alpha,6-\alpha]$		
Max. Phosphorus	$[1+\alpha,10-\alpha]$	$[0+\alpha,2-\alpha]$	$[4+3\alpha,17-3\alpha]$		

Now, the (UB) problem of the fully interval transportation problem with additional impurity constraints is given below:

	Works j			Tons available	Phosphoru s contents
	1	2	3		
1	$7-3\alpha$	$6-3\alpha$	$3-\alpha$	$5-\alpha$	$3-\alpha$
Ore i, 2	$7-3\alpha$	$7-\alpha$	$10-3\alpha$	$6-\alpha$	$2-\alpha$
3	$10-3\alpha$	$7-3\alpha$	$7-\alpha$	$7-\alpha$	$0-0\alpha$
Tons required	$6-\alpha$	$6-\alpha$	$6-\alpha$		
Max. Phosphorus	$10-\alpha$	$2-\alpha$	$17-3\alpha$		

Now, an optimal solution to the (UB) problem by the floating point method [14] is obtained as $y^{\circ}_{13} = 5-\alpha$, $y^{\circ}_{21} = 5-\alpha$, $y^{\circ}_{23} = 1+0\alpha$, $y^{\circ}_{31} = 1+0\alpha$, $y^{\circ}_{32} = 6-\alpha$ and $Z_2 = 112-54\alpha$.

Now, the (LB) problem of the fully interval transportation problem with additional impurity constraints is given below:

	Works j			Tons available	Phosphorus contents
	1	2	3		
1	$1+\alpha$	$0+\alpha$	$0+\alpha$	$1+\alpha$	$0+\alpha$
Ore i, 2	$1+\alpha$	$2+\alpha$	$3+2\alpha$	$2+\alpha$	$0+\alpha$
3	$3+2\alpha$	$1+\alpha$	$2+\alpha$	$3+\alpha$	$0+0\alpha$
Tons required	$2+\alpha$	$2+\alpha$	$2+\alpha$		
Max. Phosphorus	$1+\alpha$	$0+\alpha$	$4+3\alpha$		

and $x_{ij} \le y^{\circ}_{ij}$, for all i = 1,2,…,m and j = 1,2,…,n.

Now, an the optimal solution to the problem (LB) by the floating point method [14] is obtained as $x^{\circ}_{13} = 1+\alpha$, $x^{\circ}_{21} = 1+\alpha$, $x^{\circ}_{23} = 1+0\alpha$, $x^{\circ}_{31} = 1+0\alpha$, $x^{\circ}_{32} = 2+\alpha$ and $Z_1 = [9+13\alpha]$.

Therefore, an optimal solution to the fully interval transportation problem with additional impurity constraints is $[x^{\circ}_{13}, y^{\circ}_{13}] = [1+\alpha, 5-\alpha]$, $[x^{\circ}_{21}, y^{\circ}_{21}] = [1+\alpha, 5-\alpha]$, $[x^{\circ}_{23}, y^{\circ}_{23}] = [1+0\alpha, 1+0\alpha]$, $[x^{\circ}_{31}, y^{\circ}_{31}] = [1+0\alpha, 1+0\alpha]$, $[x^{\circ}_{32}, y^{\circ}_{32}] = [2+\alpha, 6-\alpha]$ and $[Z_1, Z_2] = [9+13\alpha, 112-54\alpha]$.

Thus, a fuzzy optimal solution for the given fully fuzzy transportation problem with additional impurity constraints is $\tilde{x}_{13} = (1,2,4,5)$, $\tilde{x}_{21} = (1,2,4,5)$, $\tilde{x}_{23} = (1,1,1,1)$, $\tilde{x}_{31} = (1,1,1,1)$, $\tilde{x}_{32} = (2,3,5,6)$ with the fuzzy objective value $\tilde{z} = (9,22,58,112)$.

5. Conclusion

An interval transportation problem with additional impurity constraints is discussed in this paper. We propose an appropriate method, namely split and bound method which has been developed without considering the midpoint and width of the intervals and is based on floating point method [14]. We have described two numerical illustrations one referring to the coal shipping problem for interval transportation problem with additional impurity constraints and the other referring to the processing of iron ore for fuzzy transportation problem with additional impurity constraints in this paper. The split and bound method provides an appropriate solution to transportation problems with additional impurity constraints having imprecise parameters which helps the decision makers to arrive at the correct managerial decisions.

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