



## A STUDY OF OPTIMIZATION OF BI-CRITERIA FUZZY TRANSPORTATION PROBLEM

### Mathematics

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### ABSTRACT

Main concept this paper to analyses the optimization of Bi-criteria bottleneck transportation problem under fuzzy environmental. This paper proposes a procedure for solving Bi-criteria in fuzzy transportation problem where the transportation time, source and destination parameters have been expressed as exponential fuzzy numbers by the decision maker. An algorithm is developed to obtain the optimal solution as exponential fuzzy number, which enables the decision maker to obtain more informing results and wider knowledge on the problem under consideration. A numerical example is solved to check the validity of the proposed procedure.

### KEYWORDS

Bi-criteria, fuzzy transportation problem, fuzzy number, exponential membership function, graded mean integration representation

### 1.Introduction

The time minimizing transportation problem is encountered in connection with transportation perishable goods, with the delivery of emergency supplies fire services, ambulance services or when military units are to be sent from their basis to the fronts. The time minimization transportation problem also known as the bottleneck transportation problem has already been studied by Arora and Puri[1], Burkard et al. [5] Garfrinkle and Rao[6], Hammer[8], Iserman[10],Szwarc[18], Mathur and Puri [11] and H.L. Bhatia, swarup kanti, M.C. Puri[4] and others.

There are two types of problems regarding the transportation time[19]:(i) minimization of the total transportation time (linear function, as aggregate the products of transportation time and quantity) called minimization of 1<sup>st</sup> transportation time and (ii) minimization of the transportation time of the longest active transporting route (non linear function) called minimization of 2<sup>nd</sup> transportation time or problem of Barasov[3]. For (ii), the total number of units on transportation operation with longest time is minimized in [8]. An important variant of the total transportation time problems is formulated and resolved in[12], which is also included in[20].

The transportation time of longest active transportation route(s) in problems where all destinations don't have the same importance are analyzed as the three classes single criteria and multi-criteria problems of the transportation time. The corresponding algorithms are developed in case of problems with priority according to demands of the subset of the destinations[14]. Some bicriteria transportation problems are shown too [2,13]. Another typical transportation problems are exposed in[16] and a research directive in [7].

In this paper, time minimization transportation is considered under uncertain environment due to geographic features such as low road density. A 2009 USITC report mentions that trucks in Ghana travelling from Paga (on the northern border with Burkina Faso) to Tema (on the gulf of guinea) take two to four days under normal conditions, but a week or more delays as estimated 10-20 percent of trucks. From a business or investment perspective, a long, but certain transport time may be preferable to a (potentially) shorter but unpredictable transport time.

Usually the imprecision are expressed as fuzzy numbers. In this paper, transportation time, supply, and demand is expressed as exponential fuzzy numbers, which are unlimited range of fuzzy numbers; but the generalized fuzzy numbers have a fixed range. An algorithm is developed to obtain the optimal solution as exponential fuzzy numbers. A numerical example is also given. The rest of the paper is organized as follows. Section 2 and 3 introduce the concept of exponential fuzzy number and the general arithmetic operators. Fuzzy time minimization transportation problem formulation is presented in section 4 followed by solutions in section 5. Experimental illustrations are provided in section 5 and some conclusions are provided towards the end.

### 2.Exponential fuzzy number

**Definition 2.1.**In general, a generalized fuzzy number A is described as any fuzzy subset of the real line R, whose membership function  $\mu_A$  satisfies the following conditions.

- (1)  $\mu_A$  is a continuous mapping from R to the enclosed interval[0,1]
- (2)  $\mu_A(x)=0, -\infty < x \leq C,$
- (3)  $\mu_A(x)=L(x)$  is strictly increasing on [C, a],
- (4)  $\mu_A(x)=w, a \leq x \leq b,$
- (5)  $\mu_A(x)=R(x)$  is strictly increasing on [b, d],
- (6)  $\mu_A(x)=0, d \leq x < \infty,$

Where  $0 < w \leq 1, a, b, c$  and  $d$  are real numbers.

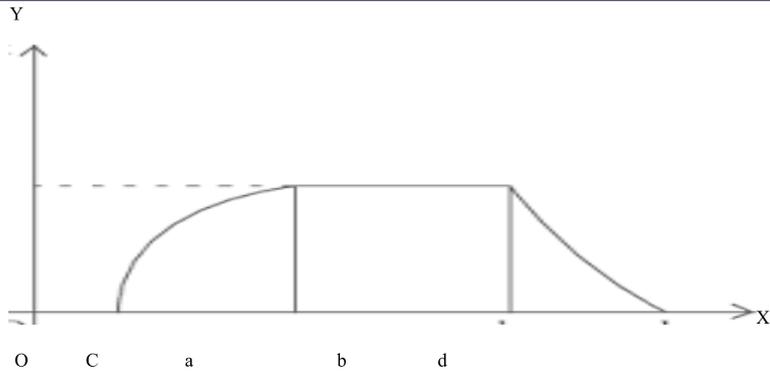


Fig.1. Generalized L.R. type fuzzy number  $A=(c, a, b, d; w)_{LR}$

We denote this type of generalized fuzzy number as  $A=(c, a, b, d; w)_{LR}$  when  $w=1$ , we denote this type of generalized fuzzy number as  $A=(c, a, b, d)_{LR}$ . Please see fig. 1 for an illustration.

However these fuzzy numbers always have a fixed range as  $[c,d]$ .

**Definition 2.2** An exponential fuzzy numbers family is unlimited range fuzzy number. We define its general form as follows

$$f_A(x) = \begin{cases} w_A \exp\{-(a_A-x)/\alpha_A\}, & x \leq a_A \\ w_A, & a_A \leq x \leq b_A \\ w_A \exp\{-(x-b_A)/\beta_A\}, & b_A \leq x \end{cases}$$

Where  $0 < w_A \leq 1$ ,  $a_A, b_A$  are real numbers and  $\alpha_A, \beta_A$  are positive real numbers. We denote this type of generalized exponential fuzzy numbers as  $(A)_E=(a_A, b_A, \alpha_A, \beta_A; w_A)_E$ . When  $w_A = 1$ , we denote it as  $(A)_E=(a_A, b_A, \alpha_A, \beta_A)_E$ . Please see fig 2. For an illustration.

**Result 2.3.** Let  $(A)_E=(a_A, b_A, \alpha_A, \beta_A; w_A)_E$  be a generalized exponential number with  $0 < w_A \leq 1$  and  $\alpha_A, \beta_A$  are positive real numbers,  $a_A, b_A$  are real numbers then the graded mean integration representation of A is  $P(A) = \frac{a_A+b_A}{2} + \frac{\beta_A-\alpha_A}{4}$

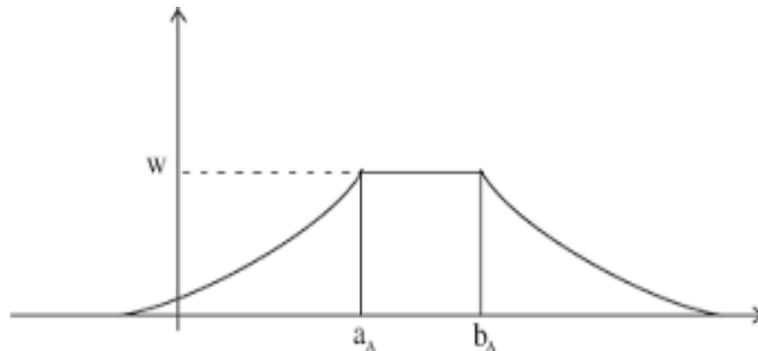


Fig .2. Exponential membership function .

**3. Generalized arithmetic operators of exponential fuzzy numbers**

Suppose that  $(A_1)_E=(a_1, b_1, \alpha_1, \beta_1, w_1)_E$  and  $(A_2)_E=(a_2, b_2, \alpha_2, \beta_2, w_2)_E$  are two generalized exponential fuzzy numbers. Let  $w = \min\{w_1, w_2\}$  some arithmetical results could be as:

- The addition of  $(A_1)_E$  and  $(A_2)_E$  is  
 $(A_1 \oplus A_2)_E=(a_1 + a_2, b_1 + b_2, \alpha_1 + \alpha_2, \beta_1 + \beta_2; w)_E$   
 Where  $a_1, b_1, a_2, b_2$  are all real numbers and  $\alpha_1, \alpha_2, \beta_1, \beta_2$  are positive .

- The multiplication of  $(A_1)_E$  and  $(A_2)_E$  is  
 $(A_1 \otimes A_2)_E=(a, b, \alpha, \beta, w)_E$   
 Where  $T = \{a_1 a_2, a_1 b_2, b_1 b_2\}$ ,  $T = \{\alpha_1 \alpha_2, \alpha_1 \beta_2, \beta_1 \beta_2\}$  and  
 $a = \min T = k^{th}$  element of T,  
 $b = \max T = l^{th}$  element of T,

Then  $a = \min T_1 = k^{th}$  element of  $T_1$ , and  
 $\beta = \max T_1 = l^{th}$  element of  $T_1$ ,  
 where  $1 \leq K \leq 4, 1 \leq l \leq 4$ .

- $(-A_2)_E=(-b_2, -a_2, b_2, a_2; w_2)_E$  then  
 $(A_1 - A_2)_E=(A_1 \oplus (-A_2))_E$   
 $= (a_1 - b_2, b_1 - a_2, \alpha_1 + \beta_2, \beta_1 + \alpha_2; w)_E$

- $(\frac{1}{A_2})_E = (\frac{1}{b_2}, \frac{1}{a_2}, \frac{1}{\beta_2}, \frac{1}{\alpha_2}; w_2)_E$

We have 
$$\left(\frac{A_1}{A_2}\right)_E = \left(A_1 \otimes \left(\frac{1}{A_2}\right)\right)_E$$

$$= \left(\frac{\alpha_1}{b_2}, \frac{b_1}{\alpha_2}, \frac{\alpha_1}{\beta_2}, \frac{\beta_1}{\alpha_2}; w\right)_E$$

Where  $\alpha_1, b_1, \alpha_2, b_2, \alpha_1, \alpha_2, \beta_1, \beta_2$  are all non-zero positive real numbers.

5. Let  $m \in R^+, (A)_E = (a, b, \alpha, \beta; w)_E$ , then  $(m \otimes A)_E = (ma, mb, m, m\beta; w)_E$ ,  
 If  $m \in R^-$ ,  $(A)_E = (a, b, \alpha, \beta; w)_E$ , then  $(m \otimes A)_E = (ma, mb, |m|\alpha, |m|\beta; w)_E$ ,

**Definition 3.1** Let  $(A_1)_E = (\alpha_1, b_1, \alpha_1, \beta_1, w_1)_E$  and  $(A_2)_E = (\alpha_2, b_2, \alpha_2, \beta_2, w_2)_E$  be two generalized exponential fuzzy numbers, then  $(A_1)_E > (A_2)_E$  if and only if  $(P(A_1))_E > (P(A_2))_E$ .

**Definition 3.2** Let  $(A_1)_E = (\alpha_1, b_1, \alpha_1, \beta_1, w_1)_E$  and  $(A_2)_E = (\alpha_2, b_2, \alpha_2, \beta_2, w_2)_E$  be two generalized exponential fuzzy numbers, then  $(A_1)_E = (A_2)_E$  if and only if  $(P(A_1))_E = (P(A_2))_E$ .

**4. Formulation of the fuzzy time minimization transportation**

Let us consider the standard balanced fuzzy transportation problem with  $m$  sources  $A_i$  (with supplies  $(a_i)_E$ ),  $i \in I = 1, 2, \dots, m$  and  $n$  destinations  $B_j$  (with demands  $(b_j)_E$ ),  $j \in J = \{1, 2, \dots, n\}$ . If  $(X_{ij})_E$  = the number of units moving from  $A_i$  to  $B_j$ , the feasible solution  $(x)_E$  and the set of feasible solution  $(x)_E$  is

$$(X)_E = \{ (x)_E \mid \sum_{j \in J} (X_{ij})_E = (a_i)_E, \forall i \in I; \sum_{i \in I} (X_{ij})_E = (b_j)_E, \forall j \in J; P(X_{ij})_E \geq 0, \forall (i, j) \}$$

$$\sum (a_i)_E = \sum (b_j)_E \tag{1}$$

i.e.,  $P(a_i)_E = P(b_j)_E$  for  $i$  to 1 to  $m$ ,  $j = 1$  to  $n$ .

suppose  $(t_{ij})_E$  = the time required for transporting all  $(X_{ij})_E$  units using corresponding routes  $(i, j)$  for all  $i \in I$  and  $j \in J$ .

Transportation efficiency  $(F(x))_E = \sum_{i \in I} \sum_{j \in J} (t_{ij})_E (X_{ij})_E$  (2)

Now we focus to the objective of minimizing the fuzzy time of active transportation routes  $(i, j)$  as

$$(T(x))_E = \sum_{i \in I} \sum_{j \in J} (t_{ij})_E h_{ij} \tag{3}$$

Where  $h_{ij}$  as auxiliary function show active and non active transportation routes (activities)

$$h_{ij} = \begin{cases} 1, & \text{if } P(X_{ij})_E > 0 \\ 0, & \text{if } P(X_{ij})_E = 0 \end{cases} \tag{4}$$

This two types of measure of transportation efficiency (2) & (3) will be called variant A (linear function) and variant B (nonlinear function) of the total time transportation problem respectively.

**5. Solution methodology**

let  $X^k$  and  $X^{k+1}$  are two basis neighbouring feasible solutions, where  $(X_{ij}^{(k)})_E$  is entering basis variable and  $(X_{is}^{(k)})_E$  is leaving basis variable for  $X^{(k)}$ .

$X^{(k)}$  contain :  $P(X_{ij}^{(k)})_E = 0$  and  $P(X_{is}^{(k)})_E > 0$ .

$X^{k+1}$  contain :  $P(X_{ij}^{(k+1)})_E > 0$  and  $P(X_{is}^{(k+1)})_E = 0$  and there is  $P(X_{ij}^{(k+1)})_E = P(X_{is}^{(k)})_E$ .

In moving from  $X^{(k)}$  to  $X^{(k+1)}$ , the fuzzy total time  $(T(x))_E$  given as (3) will be changed with following values:

$$(q_{ij}^{(k)})_E = (t_{ij})_E - (t_{is})_E \tag{5}$$

The characteristic  $(q_{ij})_E$  is the change of the transportation time in problem (3). Then the solution  $X^{(k+1)}$  has

$$(T^{(k+1)})_E = (T^{(k)})_E + (q_{ij}^{(k)})_E \tag{6}$$

Therefore the total time  $(T^{(k+1)})_E$  is determined by values  $(q_{ij}^{(k)})_E$  as follows:

$$P((T^{(k+1)})_E) = \begin{cases} > P(T^{(k)})_E & \text{if } P(q_{ij}^{(k)})_E > 0 \\ = P(T^{(k)})_E & \text{if } P(q_{ij}^{(k)})_E = 0 \\ < P(T^{(k)})_E & \text{if } P(q_{ij}^{(k)})_E < 0 \end{cases} \tag{7}$$

Let  $(T^*)_E$  be the minimum value of  $(T(x))_E$ ,  $(X^*)_E$  is the fuzzy optimal solution of (3).

$$(T^*)_E = \{(T(x))_E = \sum_{i \in I} \sum_{j \in J} (t_{ij})_E h_{ij}\} \tag{8}$$

Table 3

Various indicators

Non basic cell	Indicators $d_{ij}^{(1)}$ for F(x)	Indicators $q_{ij}^{(1)}$ for T(x)
$(x_{11}^{(1)})_E$	$d_{11}^{(1)}=(-2,6,34,35,0.7)_E$	$q_{11}^{(1)}=(4,8,18,19,0.7)_E$
$(x_{13}^{(1)})_E$	$d_{13}^{(1)}=(1,9,23,24,0.7)_E$	$q_{13}^{(1)}=(5,9,15,15,0.8)_E$
$(x_{22}^{(1)})_E$	$d_{22}^{(1)}=(5,17,38,37,0.7)_E$	$q_{22}^{(1)}=(2,6,12,12,0.8)_E$
$(x_{23}^{(1)})_E$	$d_{23}^{(1)}=(-3,23,42,42,0.7)_E$	$q_{23}^{(1)}=(-2,2,8,8,0.8)_E$
$(x_{24}^{(1)})_E$	$d_{24}^{(1)}=(7,9,39,38,0.7)_E$	$q_{24}^{(1)}=(4,8,13,13,0.7)_E$
$(x_{25}^{(1)})_E$	$d_{25}^{(1)}=(0,6,23,21;0.7)_E$	$q_{25}^{(1)}=(-2,0,7,5,0.7)_E$
$(x_{31}^{(1)})_E$	$d_{31}^{(1)}=(2,8,43,42,0.7)_E$	$q_{31}^{(1)}=(5,9,19,19,0.8)_E$
$(x_{34}^{(1)})_E$	$d_{34}^{(1)}=(0,8,18,16,0.7)_E$	$q_{34}^{(1)}=(1,5,10,9,0.7)_E$
$(x_{35}^{(1)})_E$	$d_{35}^{(1)}=(-1,7,22,21,0.7)_E$	$q_{35}^{(1)}=(0,4,14,14,0.8)_E$
$(x_{42}^{(1)})_E$	$d_{42}^{(1)}=(-3,5,21,21,0.8)_E$	$q_{42}^{(1)}=(-1,3,9,9,0.8)_E$
$(x_{43}^{(1)})_E$	$d_{43}^{(1)}=(-5,7,34,33,0.7)_E$	$q_{43}^{(1)}=(1,5,11,12,0.7)_E$
$(x_{44}^{(1)})_E$	$d_{44}^{(1)}=(-3,5,17,20,0.7)_E$	$q_{44}^{(1)}=(-1,3,8,7,0.7)_E$

Table 4

Quality of solutions

Source/ Destinations	$B_1$	$B_2$	$B_3$	$B_4$	$B_5$
$A_1$	$(10,12,11,14;0.7)_E$ $(4,8,18,19;0.7)_E$	$(2,4,3,5;0.8)_E$ <b><math>(0,6,50,51;0.7)_E</math></b>	$(9,11,10,12;0.8)_E$ $(5,9,15,15;0.8)_E$	$(1,3,2,5;0.7)_E$ <b><math>(9,11,10,12;0.8)_E</math></b>	$(4,6,5,7;0.8)_E$ <b><math>(-4,6,77,77;0.7)_E</math></b>
$A_2$	$(1,3,2,5;0.7)_E$ $(0,2,5,7;0.7)_E$	$(6,8,7,9;0.8)_E$ $(2,6,12,12;0.8)_E$	$(2,4,3,5;0.8)_E$ $(-2,2,8,8;0.8)_E$	$(7,9,8,11;0.7)_E$ $(4,8,13,13;0.7)_E$	$(1,1,2,3;0.9)_E$ <b><math>(12,14,13,15;0.8)_E</math></b>
$A_3$	$(11,13,12,14;0.8)_E$ $(5,9,19,19;0.8)_E$	$(1,3,2,5;0.7)_E$ <b><math>(5,9,39,40;0.7)_E</math></b>	$(3,5,4,6;0.8)_E$ <b><math>(14,16,15,17;0.8)_E</math></b>	$(4,6,5,7;0.8)_E$ $(1,5,10,9;0.7)_E$	$(6,8,7,9;0.8)_E$ $(0,4,14,14;0.8)_E$
$A_4$	$(8,10,9,11;0.8)_E$ <b><math>(12,18,43,45;0.8)_E</math></b>	$(3,5,4,6;0.8)_E$ $(-1,3,9,9;0.8)_E$	$(5,7,6,9;0.7)_E$ $(-1,3,13,14;0.7)_E$	$(2,4,3,5;0.8)_E$ $(-4,0,10,10;0.8)_E$	$(4,6,5,7;0.8)_E$ <b><math>(-3,5,61,61;0.7)_E</math></b>

Table 5

Quality of solutions

Source/ Destinations	$B_1$	$B_2$	$B_3$	$B_4$	$B_5$
$A_1$	$(10,12,11,14;0.7)_E$ $(7,11,16,16;0.7)_E$	$(2,4,3,5;0.8)_E$ <b><math>(0,6,50,51;0.7)_E</math></b>	$(9,11,10,12;0.8)_E$ $(5,9,15,15;0.8)_E$	$(1,3,2,5;0.7)_E$ <b><math>(4,14,71,73;0.7)_E</math></b>	$(4,6,5,7;0.8)_E$ <b><math>(-7,11,137,137;0.7)_E</math></b>
$A_2$	$(1,3,2,5;0.7)_E$ $(-2,2,7,7;0.7)_E$	$(6,8,7,9;0.8)_E$ $(2,6,12,12;0.8)_E$	$(2,4,3,5;0.8)_E$ $(-2,2,8,8;0.8)_E$	$(7,9,8,11;0.7)_E$ $(4,8,13,13;0.7)_E$	$(1,1,2,3;0.9)_E$ <b><math>(12,14,13,15;0.8)_E</math></b>
$A_3$	$(11,13,12,14;0.8)_E$ $(8,12,17,16;0.7)_E$	$(1,3,2,5;0.7)_E$ <b><math>(5,9,39,40;0.7)_E</math></b>	$(3,5,4,6;0.8)_E$ <b><math>(14,16,15,17;0.8)_E</math></b>	$(4,6,5,7;0.8)_E$ $(1,5,10,9;0.7)_E$	$(6,8,7,9;0.8)_E$ $(0,4,14,14;0.8)_E$
$A_4$	$(8,10,9,11;0.8)_E$ <b><math>(12,18,43,45;0.8)_E</math></b>	$(3,5,4,6;0.8)_E$ $(-1,3,9,9;0.8)_E$	$(5,7,6,9;0.7)_E$ $(1,5,11,12;0.7)_E$	$(2,4,3,5;0.8)_E$ <b><math>(-3,5,61,61;0.7)_E</math></b>	$(4,6,5,7;0.8)_E$ $(0,4,10,10;0.8)_E$

$$(t^2)_E = \max \{ (t_{12})_E, (t_{14})_E, (t_{15})_E, (t_{21})_E, (t_{32})_E, (t_{33})_E, (t_{41})_E, (t_{45})_E \}$$

$$= (t_{41})_E$$

$$= (8,10,9,11;0.8)_E$$

Since  $(q_{22}^{(2)})_E = (-4,0,10,10;0.8)_E$ , i.e.,  $P(q_{22}^{(2)})_E < 0$   $(X^{(2)})_E$  is not optimal fuzzy solution of  $(T(x))_E$ . Taking  $(x_{44})_E$  as entering variable  $(x_{45})_E$  as leaving variable decrease  $(T^{(2)})_E = (24,38,32,49,0.7)_E$  to  $(T^3)_E = (22,36,32,47,0.7)_E$  which is shown in table 5.

Since all  $P(q_{ij})_E \geq 0$ , the optimal solution of  $(T(x))_E$  is reached.

$$(T^3)_E = (2,4,3,5;0.8)_E + (1,3,2,5;0.7)_E + (4,6,5,7;0.8)_E + (1,1,2,3;0.9)_E +$$

$$\begin{aligned}
& (1,3,2,5;0.7)_E + (3,5,4,6;0.8)_E + (8,10,9,11;0.8)_E + (2,4,3,5;0.8)_E \\
& = (22,36,32,47;0.7)_E \\
& (t^{(3)})_E = \max\{ (t_{12})_E, (t_{14})_E, (t_{15})_E, (t_{21})_E, (t_{32})_E, (t_{33})_E, (t_{41})_E, (t_{45})_E \} \\
& = (t_{41})_E \\
& = (8,10,9,11;0.8)_E
\end{aligned}$$

## 7. Conclusion

The time of transport might be significant factor in several transportation problems. In this paper, an algorithm is developed to solve total time minimization in fuzzy transportation problem. Optimal solution is obtained as exponential fuzzy number. This enables the decision maker to obtain more informing results and wider knowledge on the problem under consideration using the proposed algorithm, it is found that:

$$\begin{aligned}
(T^1)_E &= (20,40,32,51,0.7)_E & P((T^1)_E) &= 36.75 \\
(T^2)_E &= (24,38,32,49,0.7)_E & P((T^2)_E) &= 35.25 \\
(T^3)_E &= (22,36,32,47,0.7)_E & P((T^3)_E) &= 32.75
\end{aligned}$$

Which shows the efficiency of the proposed algorithm. In this paper, the input as well as the output is expressed as exponential fuzzy numbers, so that the proposed procedure preserves the fuzziness. The transportation efficiency and the longest time on active transportation routes are also obtained.

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