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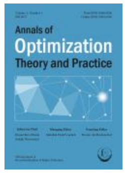

A Fuzzy multi-product two-stage supply chain network design with possibility of direct shipment

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Abstract The configuration of the supply chain network (SCN) is one of the strategic issues that have a major impact on the overall performance of the supply chain. A well designed SCN leads to an ability to reduce the supply chain total cost. These purposes are influenced by the supply chain strategy, which is based either on direct or indirect supply or shipment. In the case of direct shipment, the products are directly transported from the point of origin to the customers. In the classic transportation problems, it is usually assumed that the transportation time and costs are certain. Most existing mathematical models neglect the presence of uncertainty within a programming environment. This uncertainty might come about because of traffic jam, machine malfunctioning, defect in raw material, interpretation of various events and etc. These emprise parameters can be considering as fuzzy numbers. In this study, for the first time a mathematical model for a responsive, multi-product two-stage, SCN with possibility of direct shipment is proposed. Because of the unpredictable factors that mentioned above, cost coefficients are considered as trapezoidal fuzzy numbers. Therefore, for validation, the proposed model is coded by GAMS software. The results showed that relevant model is valid.

Keywords Supply chain network; Direct shipment; Mathematical model; Fuzzy theory

1. Introduction

During the past few decades, supply chain network design (SCND) has attracted much attention of academia and industry. Due to growing supply chains complexity in

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globalization has imposed many challenges on the supply chain management (SCM) practice, among which is to build responsive supply chains to satisfy customer demands.

It typically involves several strategic subjects about the capacity, location and number of production plants, distribution centers and other facilities. Companies in various markets emphasize such decisions to manage product flows from suppliers to customers proficiently and/or responsively.

Effective SCND requires various decisions concerning the information and products flow, carried out at strategic, tactical, and operational levels. The strategic level is related in an extensive approach with the of suppliers and location selection, and determining capacities of factories and distribution centers (DCs), raw materials and products flows, towards minimizing total costs Farahani *et al.* (2014). These decisions have an important effect on the supply chain performance, as they determine the network configuration that will be operated and controlled.

Transportation is a crucial part in SCND that is consists of transfer raw materials or products from one position to another along SCN.

The use of a responsive transfer network (RTS) can effectively reduce overall cost, delivery lead time and increase satisfaction levels of customers. RTS also prepare an appropriate platform to centralize and operate with fewer facilities. Furthermore, type of transportation mode is key element to achieve a high level of product availability at a reasonable price and cost saving.

The traditional transportation problem (TP) is special class of linear programming dealing with the transport of single commodity from several sources to several distinctions. The fixed charge problem (FCP) is one of the combinatorial optimization problem which is including two types cost, namely fixed cost and variable cost. The fixed charge transportation problem (FCTP) is an extension of the TP and is considered as one of the well-known type of transportation problem in the operations research. FCTP was first formulated by Hirsch and Dantzig (1968). FCTP take place when both fixed and variable cost are simultaneously present.

Nowadays, decisions should be viable to complex and uncertain business environments. So, it is critical to make these decisions in the presence of uncertainty. For examples, the transportation cost, the operation cost, the capacity of the facilities and the customer demand may be uncertain for a certain time period. To show such emprise data is used from fuzzy numbers, especially by triangular or trapezoidal fuzzy numbers.

According to the literature, many studies have been proposed and much research has been performed on the design and to solve fuzzy problems. Sakawa and Yano (1986) and Sakawa *et al.* (1987) investigated an interactive fuzzy decision making method using linear and non-linear membership functions for solving the multi-objective linear programming problem.

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Chanas and Kuchta (1996) studied the solution algorithm for solving the fuzzy transportation problem. Li *et al.* (1997) presented a mathematical model for a multi-objective STP with coefficients of the objective function under fuzzy environments by solving with genetic algorithm.

Jimenez and verdegay (1998) studied two types of uncertain solid transportation problems (STP), in which the supplies, demands and conveyance capacities are under interval and fuzzy environment. Jimenez and verdegay (1999) investigated a fuzzy STP (FSTP). For solving this model, they used an evolutionary algorithm-based parametric approach. Omar and Samir (2003) investigated the solution algorithm for solving the fuzzy transportation problem.

Gao and Liu (2004) presented two-phase fuzzy algorithm for multi-objective transportation problem. Samanta and Roy (2005) attempted to solve the fuzzy multi objective entropy transportation problem by employing an algorithm. Yang and Liu (2007) investigated a model for a fuzzy fixed charge solid transportation problem (FFCSTP). To solve their model, they proposed a hybrid algorithm based on the fuzzy simulation technique and Tabu search.

Lin *et al.* (2009) proposed an effective hybrid evolutionary algorithm to solve an integrated multistage logistics network model with considering the direct shipment and direct delivery of logistics and inventory.

Molla-Alizadeh-Zavardehi *et al.* (2013) first studied a model for a FFCSTP with fuzzy fixed cost transportation. To solve the proposed model, they applied three meta-heuristic algorithms, respectively variable neighborhood search and hybrid variable neighborhood search and simulated annealing. Pramanik *et al.* (2013) proposed a model for Multi-objective solid transportation problem under imprecise environments. For solving this model, they used a generalized reduced gradient method.

Liu *et al.* (2014) presented a mathematical model for a FSTP with type-2 fuzzy variables by solving with the fuzzy simulation based Tabu Search algorithm. Singh and Gupta (2014) proposed a new approach for solving cost minimization balanced transportation problem, in which coefficients of the objective function are under fuzzy environments. Rani and Gulati (2014) presented a new method for solving unbalanced fully fuzzy transportation problems.

Giri *et al.* (2015) proposed some approach for solving a fully fuzzy fixed charge multi-item STP. In a research by Pramanik *et al.* (2015) first investigated a fixed-charge transportation problem in a two-stage supply chain network under the situation of Gaussian type-2 fuzzy environments. To solve their problem, they used meta-heuristics algorithms. Mahmoodirad and sanei (2016) presented an effective optimization approach based on meta-heuristics algorithms for a multi-stage, multi-product solid supply chain network design problem.

Sanei *et al.* (2016) studied a Two-Stage Supply Chain Network problem under uncertain conditions, in which cost and some other parameters are interval numbers. They considered two different order relations and then developed two solution procedures in order relations for the interval proposed problem. Kocken and Sivri (2016) presented a model for a fuzzy solid transportation problem with fuzzy cost coefficients, fuzzy supplies, fuzzy demands and fuzzy conveyances. In their model, they proposed an approach to generate all optimal solutions parametrically. In a research by Ebrahimnejad (2016) a new method proposed to solve fuzzy TP in which the transportation cost and values of supplies and demands are deterministic by non-negative LR flat fuzzy numbers.

Pishvaee *et al.* (2011) studied the responsible supply chain network design problem (SCNDP) with possibility direct shipment to solve the proposed model; they proposed a graph theoretic-based heuristic algorithm to solve it. Until now, none has considered the fuzzy, multi-product two-stage supply chain network design with possibility of direct shipment. Hence, for the first time, we proposed a novel mathematical programing approach to solve it.

2. Formulation

The SCNDP considered in this paper is a multi-product, two stage, where it consists of plants, distribution centers (DCs) and customers. As shown in figure 1, the types of products shipped from plants to distribution centers and are delivered to the final customers or directly are delivered to customers through plants. Also result of this study must be considered the location of plants, the location of DCs and flow volume between different facilities and the best shipment strategy to minimize total transportation cost.

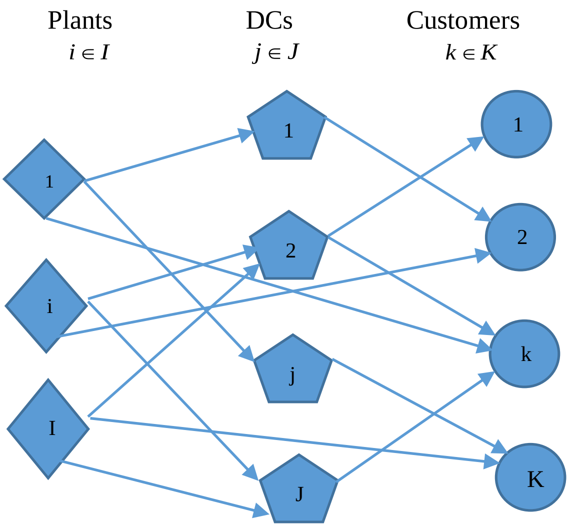

Figure1. Structure of the considered supply chain network.

Indices

I	set of plants (i = 1,2,…,I)
J	set of DCs (j = 1,2,…,J)
K	set of customers (k = 1,2,…,K)
S	set of products (s = 1,2,…,S)

Parameters

d_{ks}	Demand of product s for customer k
f_i	Fixed cost of opening plant
g_i	Fixed cost of opening distribution center
a_{ijs}	Unit transportation cost for product s from plant i to distribution center j
b_{jks}	Unit transportation cost for product s from distribution center j to customer k
c_{iks}	Unit transportation cost for product s from plant i to customer k
p_{is}	Unit Production cost for product s at plant i
e_{js}	Unit Material handling cost for product s at distribution center j
h_i	Maximum capacity for plant i
m_j	Maximum capacity for distribution center j
θ_i	Penalty cost per unit of non-utilized capacity at plant i
β_j	Penalty cost per unit of non-utilized capacity at distribution center j

Variables

X_{ijs}	Quantity of product s shipped from plant i to distribution center j
Y_{ijs}	Quantity of product s shipped from distribution center j to customer k
Z_{iks}	Quantity of product s shipped directly from plant i to customer k
W_i	$\begin{cases} 1 \text{ if a plant is opened at location } i; \\ 0 \text{ Otherwise} \end{cases}$
V_j	$\begin{cases} 1 \text{ if a distribution center opened at location } j; \\ 0 \text{ Otherwise} \end{cases}$

The mathematical model problem is as follows:

$$\min\ z = \sum_i f_i W_i + \sum_j g_j V_j + \sum_i \sum_j \sum_s \left(p_{is} + a_{ijs}\right) X_{ijs} + \sum_j \sum_k \sum_s \left(e_{js} + b_{jks}\right) Y_{jks} + \sum_i \sum_k \sum_s \left(p_{is} + c_{iks}\right) Z_{iks} + \sum_{i \in I} \theta_i \left[W_i h_i - \left(\sum_{j \in J} \sum_{s \in S} X_{ijs} + \sum_{k \in K} \sum_{s \in S} Z_{iks} \right) \right] + \sum_{j \in J} \beta_j \left(\sum_{j \in J} V_j m_j - \sum_{k \in K} \sum_{s \in S} Y_{jks} \right) \tag{1}$$

subject to

$$\sum_i z_{i,k,s} + \sum_j Y_{j,k,s} = d_{ks} \qquad \forall k,s \qquad (2)$$

$$\sum_i \sum_s X_{ijs} = \sum_k \sum_s Y_{jks} \qquad \forall j \qquad (3)$$

$$\sum_k \sum_s Z_{iks} + \sum_j \sum_s X_{ijs} \le W_i h_i \qquad \forall i \qquad (4)$$

$$\sum_k \sum_s Y_{jks} \le V_j m_j \qquad \forall j \qquad (5)$$

$$W_i, V_j \in \{0,1\} \qquad \forall i, j \qquad (6)$$

$$X_{ijs}, Y_{jks}, Z_{iks} >= 0 \qquad \forall i, j, k, s \qquad (7)$$

In this model, objective function (1) minimizes the total cost of supply chain network including charge opening cost associated with facility, processing cost, penalty cost for non-utilized capacities at plants and distribution, transportation cost.

Constraint (2) guarantees that all the demand of customers must be met. A constraint (3) guarantees the sum of products that is shipped from the plants to the DCs should be equal to the amount products that are distributed from the DCs to the customers. Constraints (4), (5) represent capacity equations for plants and DCs. Constraints (6) include the binary constraints. Constraints (7) enforce positivity restrictions on the real-valued variables. When, the costs cannot be determined precisely, the objective function could be considered as a Fuzzy number. In this study, assume that, the cost coefficients are imprecise, also objective function turns to a fuzzy objective function and can be stated as follows:

$$\begin{aligned} \min \ z = & \sum_i \tilde{f}_i W_i + \sum_j \tilde{g}_j V_j + \sum_i \sum_j \sum_s \left(\tilde{p}_{is} + \tilde{a}_{ijs} \right) X_{ijs} + \sum_j \sum_k \sum_s \left(\tilde{e}_{js} + \tilde{b}_{jks} \right) Y_{jks} \\ & + \sum_i \sum_k \sum_s \left(\tilde{p}_{is} + \tilde{c}_{iks} \right) Z_{iks} + \sum_{i \in I} \tilde{\theta}_i \left[W_i h_i - \left(\sum_{j \in J} \sum_{s \in S} X_{ijs} + \sum_{k \in K} \sum_{s \in S} Z_{iks} \right) \right] + \\ & \sum_{j \in J} \tilde{\beta}_j \left(\sum_{j \in J} V_j m_j - \sum_{k \in K} \sum_{s \in S} Y_{jks} \right) \end{aligned} \qquad (8)$$

Since trapezoidal fuzzy numbers are used to show the fuzzy costs, the total cost of objective function will also be trapezoidal fuzzy number. Now we want to apply a method for ranking of trapezoidal fuzzy numbers which is used by Basirzadeh et al. (2008). The trapezoidal fuzzy number $\tilde{A}(a.b.c.d)$ with a piecewise linear membership function, its rank is calculated as follows:

$$Rank(\tilde{A}) = \frac{a+b+c+d}{4}$$

3. Mathematical Model using GAMS software

To survey the validation of proposed model, a small size problem with GAMS software is solved. Problem parameters are given table1.

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Table 1. The parameters of problem.

i=2	*j*=2		*K*=3	*S*=2
f1(*i*)	200	150	p3(*i*,*s*)	5 7 6 6
f2(*i*)	300	250	p4(*i*,*s*)	6 8 7 7
f3(*i*)	400	350	e1(*j*,*s*)	2 2 2 4
f4(*i*)	450	370	e2(*j*,*s*)	4 3 3 5
g1(*j*)	50	60	e3(*j*,*s*)	5 4 4 6
g2(*j*)	80	70	e4(*j*,*s*)	6 5 5 7
g3(*j*)	90	80	a1(*i*,*j*,*s*)	2 4 3 3 1 2 1 4
g4(*j*)	95	85	a2(*i*,*j*,*s*)	3 5 4 5 2 4 2 5
θ1(*i*)	5	8	a3(*i*,*j*,*s*)	4 6 5 7 3 6 3 6
θ2(*i*)	10	10	a4(*i*,*j*,*s*)	5 7 6 8 4 8 4 7
θ3(*i*)	13	11	b1(*j*,*k*,*s*)	1 4 3 1 2 4 2 2 1 4 4 1
θ4(*i*)	14	12	b2(*j*,*k*,*s*)	2 5 4 2 4 5 3 3 2 5 5 5
β1(*i*)	2	4	b3(*j*,*k*,*s*)	3 6 5 3 6 6 4 4 3 6 6 6
β2(*i*)	4	6	b4(*j*,*k*,*s*)	4 7 6 4 7 7 5 5 4 7 7 7
β3(*i*)	6	7	c1(*i*,*k*,*s*)	1 4 6 1 2 4 8 6 1 5 4 5
β4(*i*)	7	8	c2(*i*,*k*,*s*)	9 7 7 4 4 5 7 7 9 6 5 7
p1(*i*,*s*)	1 2	5 4	c3(*i*,*k*,*s*)	10 8 8 6 7 6 14 8 10 7 11 8
p2(*i*,*s*)	3 4	6 5	c4(*i*,*k*,*s*)	16 11 11 8 10 9 15 11 16 10 7 9

The GAMS mathematical programming code for the problem is presented as follows:

```
sets
       i "Number of plants" /1*2/
       j "Number of DCs" /1*2/
       k "Number of customers" /1*3/
```

```
        s "number of products"  /1*2/;

parameters

h(i)    /1   3000
         2   5000/

m(j)    /1   1500
         2   1000/

f(i)    /1   337.5
         2   280/

g(j)    /1   78.75
         2   73.75/

θ(i)    /1   10.5
         2   10.25/

β(j)   / 1   4.75
         2   6.25/;

table    d(k,s)
    1      2
1   800    900
2   700    900
3   500    1000;

table p(i,s)
    1      2
1   3.75   6.5
2   4.75   5.5;

table  e(j,s)
      1        2
1     4.25     3.5
2     3.5      5.5 ;

table a(i,j,s)
      1.1   1.2  2.1 2.2
1     3.5   5.5  4.5 5.75
2     2.5   5    2.5 5.5;

table b(j,k,s)
      1.1   1.2  2.1 2.2  3.1  3.2
1     2.5   5.5  4.5 2.5  4.75 5.5
2     3.5   3.5  2.5 5.5  5.5  4.75;

table c(i,k,s)
```


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```
      1.1   1.2  2.1 2.2  3.1  3.2
1     9     7.5  8   4.75 5.75 6
2     11    8    9   7    6.75 7.25;

variables
cost
x(i,j,s)
y(j,k,s)
z(i,k,s)
w(i)
v(j);

positive variable  x,y,z;
binary variable  w,v;

Equations
Obj
const1,const2,const3,const4;

Obj..
cost=e=(sum(i,f(i)*w(i))+sum(j,g(j)*v(j))+sum((i,j,s),(p
(i,s)+
a(i,j,s))*x(i,j,s))+sum((j,k,s),(e(j,s)+b(j,k,s))*y(j,k,
s))+sum((i,k,s),(p(i,s)+c(i,k,s))*z(i,k,s))+sum(i,
θ(i)*(w(i)*h(i)-
(sum((j,s),x(i,j,s))+sum((k,s),z(i,k,s)))))+sum(j,β(j)*(
v(j)*m(j)-sum((k,s),y(j,k,s)))));

const1(k,s)..  sum((i),z(i,k,s))+sum((j),y(j,k,s)) =e=
d(k,s);
const2(j)..    sum((i,s),x(i,j,s))-sum((k,s),y(j,k,s))
=e= 0;
const3(i)..
sum((k,s),z(i,k,s))+sum((j,s),x(i,j,s))=l= w(i)*h(i);
const4(j)..    sum((k,s),y(j,k,s))=l= v(j)*m(j);
model supplychain /obj,const1,const2,const3,const4/;
solve supplychain minimizing cost using mip;

File  supplychain_Model /Results2.txt/
puttl supplychain_Model  'Title '  System.title, @60
'Page ' System.page;
put   supplychain_Model;
put /;
solve supplychain using MIP minimizing cost;
display "solution",x.l,y.l,z.l ,w.l,v.l,cost.l;
```

The Numerical results are as follow:

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Table 2. The obtained results of problem solved.

Variable	Level	Variable	Level
X(1,1,1)	0	Y(2,3,1))	0
X(1,1,2)	0	Y(2,3,2)	0
X(1,2,1)	0	Z(1,1,1)	0
X(1,2,2)	0	Z(1,1,2)	0
X(2,1,1)	1500	Z(1,2,1)	0
X(2,1,2)	0	Z(1,2,2)	0
X(2,2,1)	1000	Z(1,3,1)	0
X(2,2,2)	0	Z(1,3,2)	0
Y(1,1,1)	600	Z(2,1,1)	0
Y(1,1,2)	0	Z(2,1,2)	800
Y(1,2,1)	0	Z(2,2,1)	0
Y(1,2,2)	900	Z(2,2,2)	0
Y(1,3,1)	0	Z(2,3,1)	500
Y(1,3,2)	0	Z(2,3,2)	1000
Y(2,1,1)	200	W(1)	0
Y(2,1,2)	100	W(2)	1
Y(2,2,1)	700	V(1)	1
Y(2,2,2)	0	V(2)	1

4. Conclusion

This paper studied a responsive, multi-product, two-stage, supply chain network design problem with possibility of direct shipment under fuzzy environments for the first time. Hence, a novel mathematical model is proposed and then is coded by GAMS commercial software to solve. Obtained results showed that the model is valid. There are various avenues of research for extending the current work. One possible extension could be considering multiple periods for the relevant problem. Also we can consider type-2 fuzzy numbers or triangular fuzzy numbers instead of trapezoidal fuzzy numbers.

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