Multi Objective supply chain network design considering customer satisfaction

M. Bashiri[1], H. Khorasani[2], M. Shiri[3]
[1]Department of Industrial Engineering, University of Shahed, Tehran, Iran
[2]Department of Industrial Engineering, Eyvanekey institute of higher education, Tehran, Iran
[3]Department of Industrial Engineering, Shahed University, Tehran, Iran
(bashiri@shahed.ac.ir, mohakhorasani@gmail.com, m.shiri@shahed.ac.ir)

Abstract – **In this paper a supply chain network is designed considering multiple objectives. The first objective contains total establishment and transportation costs as well as previous works while facilities depreciation costs are considered in the network. In the second objective customer satisfaction is considered which include the fill rate and the delivered products quality. Then an epsilon-constraint approach is applied to find Pareto optimal solutions comparing to the obtained non-dominated solutions by weighted sum method. Finally some sensitivity analysis is performed to check the model validity. It confirms the validity of the proposed model.**

Keywords – **Depreciation, Epsilon-constraint, Fill-rate, Quality, Supply chain.**

I. INTRODUCTION

In recent years, supply chain network design has attracted the researcher's attention. Supply chain network including suppliers, manufacturing plants, distribution warehouses and demand markets convert raw materials to products and distributes these products to customers. The issues and limitations that can consider in supply chain network include multi-objective, multi-commodity, multi-period, multi-echelon, lead times, mode selection, stochastic programming, location and capacity of suppliers, plants, warehouses and stores and about objective functions, lower total costs, higher quality, better customer services, higher fill rate are focused.

In this paper, a facility location and allocation model is presented for a general supply chain network. The model is designed for suppliers, manufacturing plants, distribution warehouses and demand markets. The aim is to know how many and which plants and warehouses should be opened, how much raw materials from which suppliers should be bought by plants , how much products from which plants should be delivered by warehouses and how much products from which warehouses should be received by demand markets. The objective functions minimize the total establishments and transportations costs and maximize the customer's satisfaction. In this model depreciation costs are calculated in total cost and customer's satisfaction includes fill rate and quality. The model is solved by two methods including weighted sums and epsilon-constraint methods using GAMS software. The first method is a common method and the second method can produce more non-dominated solutions.

The structure of this paper is organized as follows: in section 2, the literature review is discussed. The network description is provided in section 3. The mathematical model is shown in section 4. A numerical example with sensivity analysis is presented in section 5. Finally, conclusions are discussed in last section.

II. Literature review

Sadjadi and Davoudpour presented Two-echelon, multi-commodity supply chain network design that considered mode selection and lead times to minimizing total costs and developed a Lagrangian based heuristic solution algorithm for solving the real-sized problems [1]. Zanjirani Farahani and Elahipanah considered a three-echelon supply chain, with two objective functions: minimizing costs, and minimizing the sum of backorders and surpluses of products in all periods and they presented a hybrid non-dominated sorting genetic algorithm for solving real-size problems [2]. A stochastic supply chain design developed by Azaron, brown, Tarim and Modarres. They considered risk with three objective functions: minimization of the costs, minimization of the variance of total cost and minimization of the financial risk. They used the goal attainment technique to obtain the Pareto- optimal solutions [3]. Wang, Lai and Shi proposed a multi-objective model that considered total costs and environment influence in function [4]. A multi-echelon supply chain network with location and allocation decisions developed by Latha Shankar, Basavarajappa, Chen and Kadadevaramath that optimized these two objectives simultaneously: minimizing total costs and maximizing fill rate. They solved the problem using swarm intelligence based Multi-objective Hybrid Particle Swarm Optimization (MOHPSO) algorithm [5]. Hassanzadeh Amin and Zhang presented a stochastic closed-loop supply chain network that minimize the total costs. The model is extended to consider environmental factors by weighted sums and epsilon-constraint methods [6]. In the most researcher papers, minimizing the total costs is one of the objectives but depreciation cost has not considered in any of them. In this paper, the depreciation costs are considered in addition to other costs. In second objective, customer satisfaction, we consider fill rate and the delivered products quality simultaneously.

III. Network description

In this section, a general supply chain network is described. Fig. 1 shows the network which includes suppliers, plants, warehouses and demand markets. This work considers a general supply chain network consisting of four different levels. Suppliers are on the first level, raw materials after producing from suppliers are transmitted to the second level, plants. The material in the manufacturing process is converted into the desired product, and they are transmitted to the third level warehouses. Finally products are transported from warehouses to the markets.

The objective functions are related:

_ To minimize total cost which includes transportation of raw material, plant location, production and inventory costs in plant, distribution cost from plant to warehouse, holding cost in warehouse, distribution cost from warehouse to demand market and depreciation costs that includes depreciation cost of suppliers and plants.

_ To maximize the customer's satisfaction which includes fill rate and delivered products quality. Product fill rate is the fraction of product demand that is satisfied. In quality, the aim is reduction of distance between best quality and real quality.

IV. Mathematical model

The used model in this paper is a development of the model presented in [5]. The notations used and decision variables in this model are listed in Table 1 with their description.

Table1:Notations and decision variables

Notations used	*Meaning*
sets	
L	*Number of suppliers (h=1,2,.....,l)*
N	*Number of plants (i=1,2,…….,n)*
T	*Number of warehouse locations (e=1,2,..,t)*
M	*Number of customer markets (j=1,2,…,m)*
parameters	
d_j	*Demand from market j*
f_i	*Annualized fixed cost of keeping plant i open/year*
f_e	*Annualized fixed cost of keeping warehouse e open/year*
C_{hi}	*Cost of making and shipping a component c from supply source h to plant i/unit*
C_{ie}	*Cost of producing, stocking and shipping one unit from plant i to warehouse e*
C_{ej}	*Cost of throughput and shipping one unit from warehouse e to customer market j*
PE	*Number of plants should be opened*
PI	*Number of warehouses should be opened*
C_h	*Surplus shipping depreciation cost for supply center h/unit*
C_i	*Surplus shipping depreciation cost for plant i/unit*
C_e	*Surplus shipping depreciation cost for warehouse e/unit*
q_i	*Quality of the production plant i/unit*
lq	*Minimum quality score of final product*
U_h	*Upper flow limit without depreciation for supplier h/unit*
U_i	*Upper flow limit without depreciation for plant i/unit*
U_e	*Upper flow limit without depreciation for warehouse locations e/unit*
A_h	*The surplus flow which will lead to depreciation in supplier h*
A_i	*The surplus flow which will lead to depreciation in plant i*
A_e	*The surplus flow which will lead to depreciation in warehouse e*
b_h	*An auxiliary positive variable in which is zero when A_h is negative else is equal to A_h*
b_i	*An auxiliary positive variable in which is zero when A_i is negative else is equal to A_i*
b_e	*An auxiliary positive variable in which is zero when A_e is negative else is equal to A_e*
S_h	*Capacity of supplier h.*
W_1	*The weight of first objective function (Z)*
W_2	*The weight of second objective function (ZZ)*
Variables	
x_{hi}	*Quantity shipped from supplier h to plant i*

x_{ie}	*Quantity shipped from plant i to warehouse e*
x_{ej}	*Quantity shipped from warehouse e to customer market j*
y_i	*1, if plant i is opened, 0 otherwise*
y_e	*1, if warehouse e is opened, 0 otherwise*
Z	*Total cost*
ZZ	*Customer satisfaction*
Q	*Delivered product quality*
F	*Fill rate*

The problem is given below as the following mixed integer model:

$$\min Z = \sum_{i=1}^{n} f_i y_i + \sum_{e=1}^{t} f_e y_e + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{hi} x_{hi} + \sum_{i=1}^{n}\sum_{e=1}^{t} c_{ie} x_{ie} + \sum_{e=1}^{t}\sum_{j=1}^{m} c_{ej} x_{ej} + \sum_{h=1}^{l} c_h b_h + \sum_{i=1}^{n} c_i b_i + \sum_{e=1}^{t} c_e b_e \quad (1)$$

$$\max\ ZZ = \frac{Q}{\max Q} + F \quad (2)$$

$$Q = \sum_{i=1}^{n} (q_i - lq) y_i \quad (3)$$

$$F = \sum_{e=1}^{t}\sum_{j=1}^{m} \frac{x_{ej}}{\sum_{j}^{m} d_j} \quad (4)$$

$$\sum_{i}^{n} x_{hi} \le s_h \qquad \forall h \quad (5)$$

$$0.5 \le \sum_{e=1}^{t}\sum_{j=1}^{m} \frac{x_{ej}}{\sum_{j}^{m} d_j} \le 1 \quad (6)$$

$$\sum_{h}^{l}\sum_{e}^{t} x_{hi} - x_{ie} \ge 0 \qquad \forall i \quad (7)$$

$$\sum_{i}^{n} x_{ie} - \sum_{j}^{m} x_{ej} \ge 0 \qquad \forall e \quad (8)$$

$$\sum_{i=1}^{n} y_i = PI \quad (9)$$

$$\sum_{e=1}^{t} y_e = PE \quad (10)$$

$$A_h = \sum_{i=1}^{n} x_{hi} - u_h \quad (11)$$

$$A_h \le b_h \qquad \forall h \quad (12)$$

$$A_i = \sum_{e=1}^{t} x_{ie} - u_i \quad (13)$$

$$A_i \ge M(y_i - 1) \qquad \forall i \quad (14)$$

$$A_i \le M(y_i) \quad (15)$$

$$A_i \le b_i \qquad \forall i \quad (16)$$

$$A_e = \sum_{j=1}^{m} x_{ej} - u_e \quad (17)$$

$$A_e \ge M(y_e - 1) \qquad \forall e \quad (18)$$

$$A_e \le M(y_e) \quad (19)$$

$$A_e \le b_e \qquad \forall e \quad (20)$$

Equation (1) shows the first objective function which minimizes the total cost. The total cost includes opening fixed cost of operating plants and warehouses, variable cost of production and transportation, and depreciation costs. The second objective function in Eq. (2) maximizes the customer satisfaction consisting delivered products quality in Eq. (3) and fill rate in Eq. (4). In this paper, the depreciation cost and delivered products quality are added to the model presented in [5].

The constraint (5) assures that the total quantity shipped from a supplier cannot exceed the supplier capacity. The constraint (6) shows that the allowable range of fill rate which is between %50 to %100. Constraints (7) and (8) are balancing constraints. Constraints (9) and (10) limit the number of opened plants and warehouses. Constraints (11) and (12) calculate the amount of depreciation of suppliers. Constraints (13) to (16) are related to the depreciation of plants. Constraints (17) to (20) are related to the depreciation of warehouses.

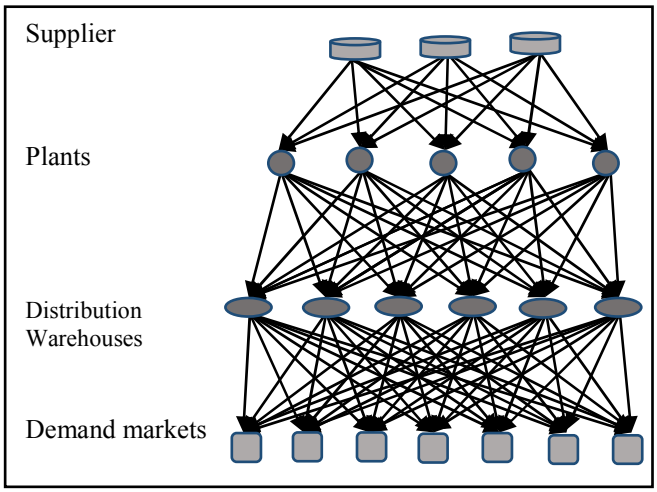

Fig 1. Four-echelon supply chain network

V. Numerical example

A. Example description

In this example it is assumed that there are 3 suppliers, 4 plants, 5 warehouses and 6 demand markets as shown in Fig. 1. The capacity of plants and warehouses is assumed to be unbounded. The quality is consist of delivered product quality. Each plant should have the minimum required quality which is 12 units of quality.

B. ε-constraint solution method

As there are two objectives in the presented model, non-dominated solutions should be achieved, so the ε-constraint method is applied. In this method, the multi-objective problem is converted to a single-objective problem with some additional constraints. One of the objective functions is considered as main objective function and other objectives are appeared as constraints. The transformed model is given below:

$$\begin{gathered} Min\ z \\ s.t; \\ zz \geq zz^{*} + \varepsilon \\ Eqs.(1) - (20) \end{gathered} \tag{21}$$

Where ε is determined small value and should be increased in different iterations.

First, the pay-off matrix is calculated. Results are shown in table 2.

Table2: Pay-off matrix in the numerical example with two objectives

	Z	*ZZ*
Z	6993.5	0.916
ZZ	14822.5	1

Then the second objective function is considered as a constraint. The Pareto solutions are obtained 10 times with ε = 0.0084 which are shown in table 3 and Fig. 2.

Table 3: Objective values for non-dominated solutions of the numerical example with the first objective as the main one

ε	Z	ZZ
0.0084	7038.871	0.924
0.0168	7082.719	0.933
0.0252	7126.567	0.941
0.0336	7170.549	0.95
0.0420	7187.038	0.958
0.0504	7227.862	0.966
0.0588	7268.686	0.975
0.0672	7309.56	0.983
0.0756	7350.888	0.992
0.0840	9517.5	1

C. Weighted sum method

As another method in achieving the non-dominated solutions, weighted sum method can be used. In that method first, all objective functions should be normalized. The objective functions are combined in a single function by multiplying their corresponding weights. The weights W_1 and W_2 are determined by decision maker. The transformed model is given below:

$$\begin{gathered} \text{Min } obj = W_1 NZ - W_2 ZZ \\ NZ = \frac{Z}{Max\ Z} \\ \text{s.t;} \\ Eqs.(1) - (20) \end{gathered} \tag{22}$$

Where *NZ* is the normalized value of *Z* while *ZZ* is normalized one as well.

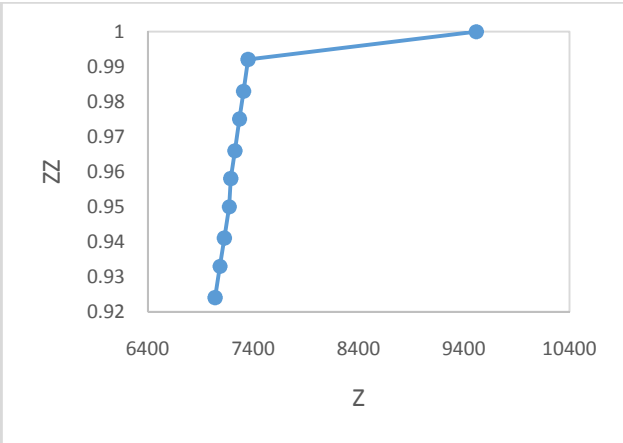

Fig 2. Pareto-front with 10 non-dominated solutions extracted by epsilon constraint showing trade-off between total cost and customer satisfaction objectives.

In this part, the problem is solved with weighted sum method by different weights. The results are shown in table 4 and Fig. 3.

Table 4 : Non-dominated solutions achieved by sum weighted method with different weights

	W_1	W_2	*Z*	*ZZ*	*NZ*
1	1	0	6999.5	0.916	0.472221
2	0.9	0.1	6999.5	0.916	0.472221
3	0.8	0.2	7404	0.999	0.499511
4	0.7	0.3	7404	0.999	0.499511
5	0.6	0.4	7404	0.999	0.499511
6	0.5	0.5	7404	0.999	0.499511
7	0.4	0.6	7404	0.999	0.499511
8	0.3	0.7	7404	0.999	0.499511
9	0.2	0.8	7404	0.999	0.499511
10	0.1	0.9	7404	0.999	0.499511
11	0.0005	0.9995	9470	1	0.638894

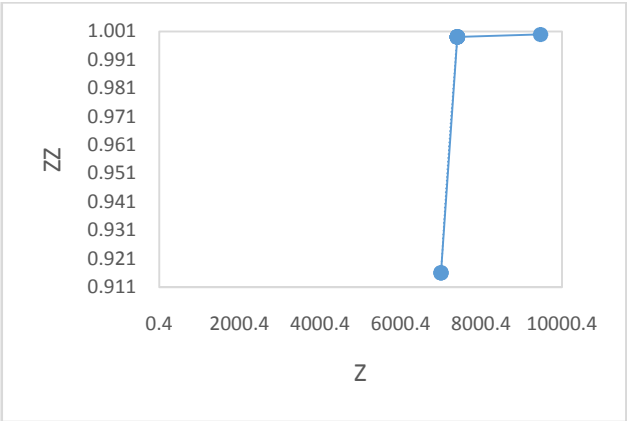

Fig 3. Pareto frontier extracted by weighted sum method for the numerical example

Comparing of Fig. 2 and Fig.3 shows that epsilon constraint method is more efficient than weighted sum method for achieving non-dominated solutions while number of extracted solutions by epsilon constraint is more than the sum weighted method. Moreover most of solutions achieved by weighted sum method can be observed in solutions of extracted by epsilon constraint method.

As a sensitivity analysis by increasing of depreciation cost of each node the optimal network tends to increase opened facilities and increase number of active links and it confirms that depreciation in the network should be considered and ignoring of that concept will achieve an inefficient supply chain network.

VI. Conclusion

In this paper a multi-echelon supply chain network is designed considering two objectives. The first objective contains total costs including fixed establishment, transportation between pair of nodes and depreciation costs. In the second objective customer satisfaction is considered which include the fill rate and the delivered products quality. Then a numerical example is solved by epsilon-constraint and weighted sum approaches to achieve non-dominated solutions. The analysis confirms that the epsilon constraint method is more efficient than weighted sum method in extracting of non-dominated solutions for a supply chain network design problem with two objectives.

As a future research depreciation cost can be included for between nodes links. Moreover considering of the problem with fuzzy parameters can be considered as well.

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