A Fuzzy Approach for a Supply Chain Network Design Problem

Can Celikbilek (cc340609@ohio.edu), Bulent Erenay and Gursel A. Suer, PhD*

Department of Industrial & Systems Engineering,
Russ College of Engineering, Ohio University
Athens, Ohio, USA, 45701

Abstract

This paper discusses a fuzzy mixed integer linear programming (FMILP) approach for a supply chain network design problem. Two conflicting objectives were considered in this study. The first objective was to maximize the total net profit associated with the supply chain network design and the second objective was to minimize the total risks associated with that. Different weights and satisfaction levels were considered and the ultimate objective was to maximize the total satisfaction level. Various risks were considered in this study and those are; distribution center location risks, transportation risks between manufacturing facilities and distribution centers and transportation risks between distribution centers and customers. The preliminary results indicated that, although it is profitably favorable to locate distribution centers in certain locations for a better supply chain design, due to the transportation and the location risks, the supply chain network is designed differently to satisfy both objectives simultaneously.

Keywords: Fuzzy Logic, Supply Chain Network Design, MILP

1. Introduction

Supply Chain Management (SCM) involves decisions regarding relationships between entities of a supply chain such as suppliers, warehouses, distributors, manufacturers and retailers. Amount of products shipped among these entities, resources and facilities allocated for these products are handled as a network design problem and hence Supply Chain Network Design (SCND) plays a critical role in overall efficiency of supply chains. Figure 1 shows the generic supply entities of a classical supply chain network.

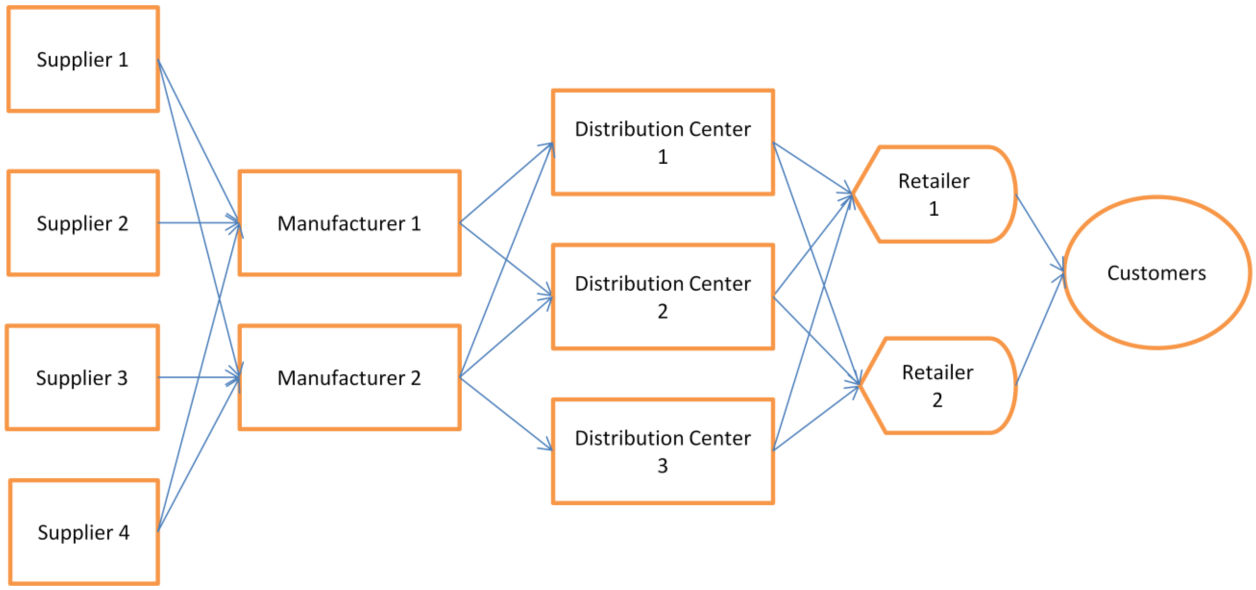


Figure 1: A generic supply chain network

Supply Chain Network Design decisions are considered as strategic level decisions as it is usually expensive and time consuming to change these decisions. Any decision at this level affects the efficiency of tactical and operational level decisions. Supply chain networks face many risk factors at each tier of the supply chain. These risks can originate from external factors such as natural disasters, weather conditions, terrorism and wars, cyber attacks to the information technology and currency fluctuations, or from internal factors such as labor strikes and failures in the information flow of the companies. Internal risk factors can be mitigated by employing effective policies within the organization, however external factors are not easy to take into account. These risk factors affects supply chain networks, thus the global economy as transportation of raw materials from suppliers to manufacturers and transportation of goods from the manufacturers to the consumers are at the center of economic activities in the world. Figure 2 represents the disruption in transportation and its possible effect in supply chain.

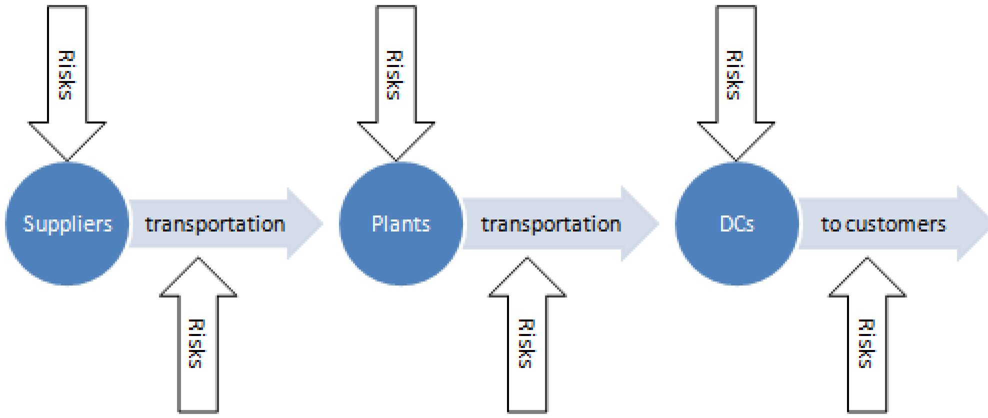


Figure 2: Potential supply chain network risk areas

Since supply chain network decisions include almost every step of a finished product from raw material suppliers to end users, even from end users to rework stations, it is impossible for one to solve this problem as a whole. Therefore, researchers generally focus on one or more aspect of this design problem and optimize the solution with respect to an objective function such as, usually cost minimization or profit maximization. Some other studies focused on supply chain risk minimization. In this study, we combine these two objectives for a production-distribution network design problem in a mixed integer linear model by using fuzzy approach. In the next section, fuzzy supply chain network design literature is discussed. In section 3, proposed fuzzy mathematical model is provided. In section 4, preliminary results are presented and concluding remarks are discussed in section 5.

2. Literature Review

In this section, a brief literature review on fuzzy supply chain network design is provided. Production-distribution networks are studied extensively in the literature. A thorough review was provided by Mula, Peidro, Diaz-Madronero and Vicens (2010) and a classification was developed based on supply chain structure, decision level, modeling approach, purpose, shared information, limitations, novelty and application. Another review was presented by presented by Fahimnia, Farahani, Marian and Luong (2013) where the studies are classified according to their solution techniques and real world applicability. Selim and Ozkarahan (2006) studied a multi-stage SCN problem considering two objectives; minimizing investment and transportation costs, and maximizing total service levels of the entire supply chain. A fuzzy goal programming approach is developed for this bi-objective problem.

Chen, Yuan and Lee (2007) proposed a two-stage fuzzy model to solve various supply chain network scenarios under uncertain demand environment with three objectives: minimizing total costs, minimizing transportation time, and maximizing robustness. Xu, He and Gen (2009) applied random fuzzy programming to supply chain network design problem where demands for the products and capacities of the suppliers are probabilistic. Genetic algorithm and spanning tree heuristic was used to solve the problem.

Gumus, Guneri and Keles (2009) integrated linear programming and neuro-fuzzy technique for multi-stage supply chain network design under uncertain demand environment. They developed simulation models to validate the supply chain networks designed by the proposed methodology. Mahnam , Yadollahpour, Famil-Dardashti and Hejazi (2009) considered fuzzy demands and fuzzy reliability of suppliers while solving a bi-objective supply chain network problem. Particlu swarm optimization and simulation models are used to solve the problem.

Bilgen (2010) developed a fuzzy mathematical model for a production-distribution network problem in order to optimize logistic decisions in consumer merchandise manufacturing. Peidro, Mula, Jmenez and Botella (2010) proposed a fuzzy linear mathematical model to solve a tactical multi-period multi-echelon, multi-product and multi-level supply chain problem where uncertainties exist for demand, supply and processes. The model aims to minimize the total cost of production, inventory, transportation, material and idleness while meeting the customer demands along the planning period.

Jolai, Razmi and Rostami (2011) developed fuzzy goal programming method and a genetic algorithm model to solve a multi-objective production-distribution network problem. They developed a hybrid genetic algorithm and compared the results with other metaheuristics. Li and Xu (2011) solved a location-allocation problem using chance constrained programming and genetic algorithms in a random and fuzzy environment.

Paksoy, Pehlivan and Özceylan (2012) proposed a fuzzy multi-objective linear model to solve a supply chain network problem for a vegetable oil company. The model aims to minimize the total transportation costs between suppliers and silos and between warehouses and manufacturer.

Paksoy and Pehlivan (2012) studied a multi-stage supply chain network problem and proposed a fuzzy linear mathematical model which minimizes the total of transportation costs among suppliers, plants and distribution centers and late delivery penalty costs. The model optimally determines the locations and capacities of the manufacturing and distribution facilities using triangular and trapezoidal membership functions.

Wu, Wu, Zhang and Olson (2013) developed a stochastic fuzzy multi-objective model for outsourcing risk management in a three stage supply chain problem. Their model showed that the customers tend to order less when uncertainty exists. Kristianto, Gunasekaran, Helo and Hao (2014) developed a two-stage model with fuzzy shortest path to design a reconfigurable supply chain network. They then compared their method with the shortest path problem with time windows and capacity constraint and showed that it performed better in terms of CPU time. The results indicated that various aspects of fuzzy programming have been utilized in supply chain network design problem. In this paper, we tried to address the real-life problem application by considering the conflicting objectives. The ultimate objective is to maximize the total satisfaction level by maximizing the profit of supply chain design while minimizing the risks associated with location of facilities as well as the transportation risks arouse from different locations of supply chain tiers.

3. Proposed Fuzzy Mixed Integer Linear Mathematical Model with Multiple Objectives

This type of problem is modeled on a discrete network. The system design consists of set of identified origins *(j)*, hubs/consolidation terminals *(k)* and destinations *(l)*. The set of commodities *i* that move through the network are represented by the set of I. The amount of commodities *i* to be transported from origin terminal i to destination terminal k is denoted by d_{il}. There are decision variables z_k is a binary variable and equal to 1 if a consolidation terminal is located at site k. y_{kl} is a binary variable equal to 1 if the D/C k is linked to customer l. Finally, variable x_{ijkl} denotes the amount of flow for commodity *i* with origin *j*, destination l, passing through terminal *k*. The following formulation solves the network design problem, where c_{ijk}, c_{ikl} stands for the unit transportation cost between manufacturing plant to D/C and D/C to customer zones, respectively.

Fuzzy mixed integer linear programming (FMILP) was proposed. The first objective is to maximize the total net profit of the considered supply chain system (λ_1) and the second objective is to minimize the total risks associated with the supply chain structure (λ_2). The overarching goal is to maximize the total satisfaction level or maximizing the total net profit while minimizing the risks of supply chain system.

Notation:

Indices:

i	*product index*
j	*mfg. plant index*
k	*hub/ D/C index*
l	*customer index*

Parameters:

I	*number of products*
J	*number of mfg. plants*
K	*number of distribution centers*
L	*number of customers*
d_{il}	*Demand of product i in customer zone l*
sp_{il}	*Sales price of product in customer zone l*
c_{ijk}	*Unit cost of transportation for product i from any plant j to any D/C k*
c^{r}_{ijk}	*Unit transportation risk for product i from any plant j to any D/C k*
c_{ikl}	*Unit cost of transportation for product i from any D/C to any destination l*
c^{r}_{ikl}	*Unit transportation risk for product i from any D/C to any destination l*
f_k	*Fixed cost of D/C k*
r_k	*Risk associated with the establishment of D/C k*
S_{ij}	*Plant capacity for product i at plant j,*
Q_k	*D/C Capacity*

Decision variables:

X_{ijk}	*demand flow of product i from plant j to D/C k*
y_{kl}	*1 if D/C k is linked to customer zone l, 0 otherwise.*
z_k	*1 if D/C k is open, 0 otherwise.*

$$\textbf{Maximize} = \boldsymbol{\lambda_1} + \boldsymbol{\lambda_2} \tag{1}$$

Subject to

$$\left(\sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} sp_{il} * d_{il} * y_{kl}\right) - \left(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{ijk} * x_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} c_{ikl} * d_{il} * y_{kl} + \sum_{k=1}^{K} f_k * z_k\right) \tag{2}$$

$$\left(\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c^{r}_{ijk} * x_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L} c^{r}_{ikl} * d_{il} * y_{kl} + \sum_{k=1}^{K} r_k * z_k\right) \tag{3}$$

$$\sum_{k=1}^{K} x_{ijk} <= S_{ij}, \qquad \forall i, \forall j \qquad (4)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ijk} <= Q_k * z_k, \qquad \forall k, \qquad (5)$$

$$\sum_{j=1}^{J} x_{ijk} \geq \sum_{l=1}^{L} d_{il} * y_{kl}, \qquad \forall i, \forall k, \qquad (6)$$

$$\sum_{k=1}^{K} y_{kl} = 1, \qquad \forall l, \qquad (7)$$

$$y_{kl} \leq z_k \qquad \forall l, \forall k, \qquad (8)$$

$$\lambda_1 \leq 1 - \left(\frac{z_1 - ub_{z1}}{lb_{z1} - ub_{z1}}\right) \qquad (9)$$

$$\lambda_2 \leq 1 - \left(\frac{z_2 - lb_{z1}}{ub_{z1} - lb_{z1}}\right) \qquad (10)$$

$$y_{kl} \in \{0,1\} \qquad \forall k, \forall l, \qquad (11)$$

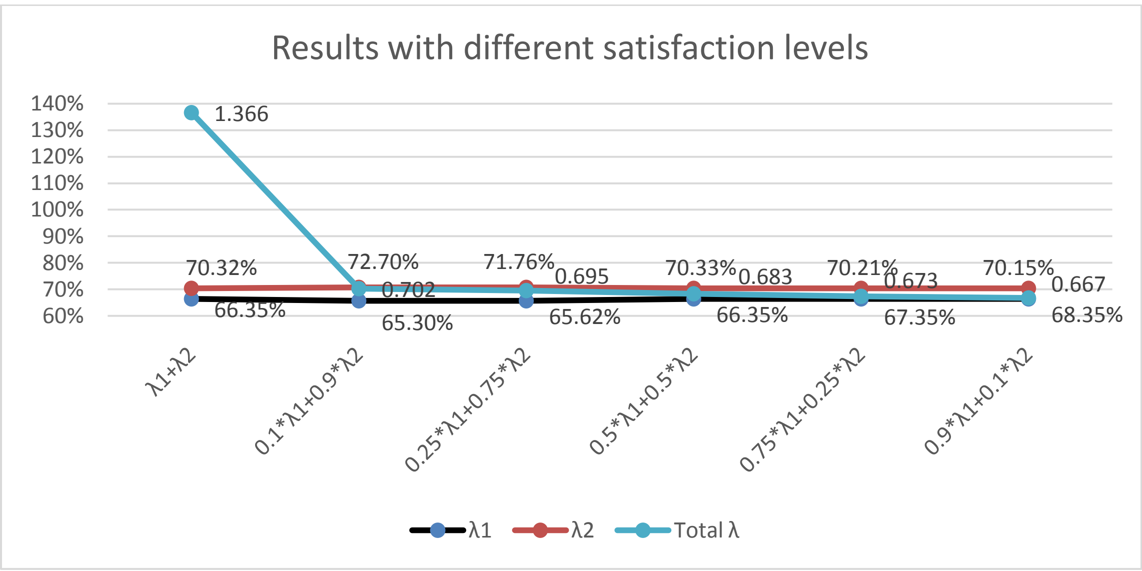
Equation (1) is the ultimate objective of this study which is the maximization of the total satisfaction level. Equation (2) aims to maximize the total net profit of the supply chain system. Equation (3) minimizes the total risks associated with supply chain system. Equation (4) ensures that manufacturing plant capacity is not exceed. Equation (5) guarantees that D/C or hub capacity is not exceeded. Equation (6) guarantee demand constraint is satisfied. Equation (7) ensures that each customer zone must be served by a single DC. Equation (8) ensures to open D/C if it serves to the customer l. Equation (9) and (10) are the linear fuzzy membership constraints. Equation (11) is the binary constraint.

4. Preliminary Experimentation and Results

The preliminary experimentation is performed with two products, three plants, four distribution centers and five customers. In order to test the validity of the proposed model, within four distribution center, second distribution center (D/C 2) is very favorable in terms of having very low fixed and transportation costs between plants and customers. However, that favorable (D/C 2) is given higher location and transportation risks compared to the others. The lower and upper bounds for each parameter are determined randomly. The results are shown in Table 1.

Table 1: Preliminary Results for different satisfaction levels

Lambda Weights	lambda1	lambda2			
	λ1	λ2	z1	z2	Total λ
λ1+λ2	66.35%	70.32%	$10,635	46.87	1.366
0.1*λ1+0.9*λ2	65.30%	72.70%	$10,531	46.69	0.702
0.25*λ1+0.75*λ2	65.62%	71.76%	$10,544	46.39	0.695
0.5*λ1+0.5*λ2	66.35%	70.33%	$10,610	46.27	0.683
0.75*λ1+0.25*λ2	67.35%	70.21%	$10,631	46.15	0.673
0.9*λ1+0.1*λ2	68.35%	70.15%	$10,640	46.08	0.667



The results for the sum of lambda values **(λ1+λ2)** are shown in the following table 2. The results are compared without risk considerations. The results indicated that when we have higher risks in D/C 2 in terms of both establishments risk and transportation risks, although that D/C is very favorable in terms of fixed cost, it is not selected due to its high total risks.

Table 2: The results for the first option (0.1*λ1+0.9*λ2)

Product	Plant	DC	Units	DC	Customer
1	1	1	7500	1	2
1	1	3	500	1	3
1	2	1	500	3	1
1	2	4	3500	3	4
1	3	3	3500	4	5
2	1	1	1800		
2	2	4	3000		
2	3	3	5500		

The results for the satisfaction levels are subject to change in different risk levels. When all the risk levels are same for all of D/Cs, all D/Cs are selected without changing other parameters.

5. Conclusions & Discussions & Future Work

This research presents preliminary results related with fuzzy mixed integer linear programming (MILP) in supply chain network design. The ultimate aim is to maximize the total net profit of the supply chain network system while minimizing the total risks associated with those decisions. The results indicated that due to different risk levels in establishment costs of facilities, transportation costs and other aspects are different. For instance, although establishing a facility in Chicago will result favorable in terms reaching out supply chain tiers, considering a harsh winter and tough transportation condition around the area can prevent establishing a facility out there. Therefore, different risk levels will play significant role in supply chain network efficiency. In terms of future work, definitely an extension with larger problems, using real life road safety and transportation safety indexes, more validation and performance analysis, sensitivity analysis and in addition to those, stochasticity, environmental aspects and many more sustainability concepts will be considered.

References

Bilgen, B. 2010. Application of fuzzy mathematical programming approach to the production allocation and distribution supply chain network problem. *Expert Systems with Applications*, *37*(6), 4488-4495.

Chen, C. L., Yuan, T. W., & Lee, W. C. 2007. Multi-criteria fuzzy optimization for locating warehouses and distribution centers in a supply chain network.*Journal of the Chinese Institute of Chemical Engineers*, *38*(5), 393-407.

Fahimnia, B., Farahani, R. Z., Marian, R., & Luong, L. 2013. A review and critique on integrated production–distribution planning models and techniques.*Journal of Manufacturing Systems*, *32*(1), 1-19.

Gumus, A. T., Guneri, A. F., & Keles, S. 2009. Supply chain network design using an integrated neuro-fuzzy and MILP approach: A comparative design study. *Expert Systems with Applications*, *36*(10), 12570-12577.

Jolai, F., Razmi, J., & Rostami, N. K. M. 2011. A fuzzy goal programming and meta heuristic algorithms for solving integrated production: distribution planning problem. *Central European Journal of Operations Research*, *19*(4), 547-569.

Kristianto, Y., Gunasekaran, A., Helo, P., & Hao, Y. 2014. A model of resilient supply chain network design: A two-stage programming with fuzzy shortest path. *Expert Systems with Applications*, *41*(1), 39-49.

Liu, Q., & Xu, J. 2011. A study on facility location–allocation problem in mixed environment of randomness and fuzziness. *Journal of Intelligent Manufacturing*, *22*(3), 389-398.

Mahnam, M., Yadollahpour, M. R., Famil-Dardashti, V., & Hejazi, S. R. 2009. Supply chain modeling in uncertain environment with bi-objective approach.*Computers & Industrial Engineering*, *56*(4), 1535-1544.

Mula, J., Peidro, D., & Poler, R. 2010. The effectiveness of a fuzzy mathematical programming approach for supply chain production planning with fuzzy demand. *International Journal of Production Economics*, *128*(1), 136-143.

Paksoy, T., & Pehlivan, N. Y. 2012. A fuzzy linear programming model for the optimization of multi-stage supply chain networks with triangular and trapezoidal membership functions. *Journal of the Franklin Institute*, *349*(1), 93-109.

Paksoy, T., Pehlivan, N. Y., & Özceylan, E. 2012. Application of fuzzy optimization to a supply chain network design: a case study of an edible vegetable oils manufacturer. *Applied Mathematical Modelling*, *36*(6), 2762-2776.

Peidro, D., Mula, J., Jiménez, M., & del Mar Botella, M. 2010. A fuzzy linear programming based approach for tactical supply chain planning in an uncertainty environment. *European Journal of Operational Research*, *205*(1), 65-80.

Selim, H., & Ozkarahan, I. 2006. Application of fuzzy multi-objective programming approach to supply chain distribution network design problem. In*MICAI 2006: Advances in Artificial Intelligence* (pp. 415-425). Springer Berlin Heidelberg.

Wu, D., Wu, D. D., Zhang, Y., & Olson, D. L. 2013. Supply chain outsourcing risk using an integrated stochastic-fuzzy optimization approach. *Information Sciences*, *235*, 242-258.

Xu, J., He, Y., & Gen, M. 2009. A class of random fuzzy programming and its application to supply chain design. *Computers & Industrial Engineering*, *56*(3), 937-950.