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Designing a supply chain management based on distributers' efficiency measurement

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ABSTRACT

This paper presents a supply chain management by considering efficiency in the system. The proposed study considers two objective functions where the first one maximizes the efficiency of the supply chain and the second one minimizes the cost of facility layout as well as production of different products. In order to measure the relative efficiency, the study uses the method developed by Klimberg and Ratick (2008) [Klimberg, R. K., & Ratick, S. J. (2008). Modeling data envelopment analysis (DEA) efficient location/allocation decisions. *Computers & Operations Research*, 35(2), 457-474.]. The study has been formulated as a mixed integer programming and the implementation of the proposed model has been demonstrated using some numerical example. The preliminary results indicate that it was possible to increase the efficiency of supply chain without increase the supply chain expenses.

1. Introduction

During the past few years, there have been tremendous efforts on developing supply chain management systems (Ganeshan & Harrison, 1995; Minner, 2003; Meixell & Gargeya, 2005; Sarkis et al., 2011; Shen, 2007; Bala, 2014). Altiparmak et al. (2006) proposed a new solution procedure based on genetic algorithms to determine the set of Pareto-optimal solutions for multi-objective supply chain network. To deal with multi-objective and enable the decision maker for evaluating a larger number of alternative solutions, two various weight approaches were implemented in the proposed solution procedure. They also presented the implementation of the proposed method for a real-world case study in Turkey. Baghalian et al. (2013) developed a stochastic mathematical formulation for designing a network of multi-product supply chains comprising several capacitated production facilities, distribution centers and retailers in markets under uncertainty. The model considered demand-side and supply-side uncertainties simultaneously. They considered a discrete set as potential locations of distribution centers and retailing outlets and investigated the effect of strategic facility location decisions on the operational inventory and shipment decisions of the supply

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chain. They used a path-based formulation, which helps consider supply-side uncertainties, which are possible disruptions in manufacturers, distribution centers and their connecting links.

Castillo-Villar et al. (2014) considered capacitated model for supply chain network design, which considers manufacturing, distribution, and quality costs. Costa et al. (2011) considered the two-level network design problem with intermediate facilities, which consists of designing a minimum cost network respecting some requirements, usually described in terms of the network topology or in terms of a desired flow of commodities between source and destination vertices. They proposed a hybrid decomposition approach, which heuristically obtains tentative solutions for the vertex facilities number and location and applied these solutions to limit the computational time of a branch-and-cut algorithm. Gan et al. (2014) discussed the transformation mechanism for formulating a multiproduct two-layer supply chain network design problem as a network flow model.

Georgiadis et al. (2011) presented an optimal design of supply chain networks under uncertain transient demand variations. Jayaraman and Pirkul (2001) presented a model for planning and coordination of production and distribution facilities for multiple commodities. Melo et al. (2006) provided a dynamic multi-commodity capacitated facility location by offering a mathematical modeling framework for strategic supply chain planning. Pierce and Giles (1997) provided a preconditioned multigrid methods for compressible flow calculations on stretched meshes. Pishvaee and Torabi (2010) presented a possibilistic programming approach for closed-loop supply chain network design under uncertainty.

Pishvaee et al. (2011) presented a robust optimization approach to closed-loop supply chain network design under uncertainty. Pishvaee et al. (2012), in other work, presented a robust possibilistic programming for socially responsible supply chain network design. Seuring (2013) provided a comprehensive review of modeling approaches for sustainable supply chain management. Syam and Côté (2010) presented a location–allocation model for service providers with application to not-for-profit health care organizations. Tang and Nurmaya Musa (2011) identified risk issues and research advancements in supply chain risk management. Finally, Xu and Nozick (2009) presented a modeling for supplier selection and the use of option contracts for global supply chain design.

2. The proposed study

Supply chain management involves three levels of strategic decisions (long-term decisions), tactical level (medium-term decisions) and operational level (decision day) (Ganeshan & Harrison, 1995). Designing a supply chain network is one of the most important strategic decisions to be taken in the initial stages of supply chain management. Supply chain design plays essential role on the supply chain network and it has an important impact on the efficiency, flexibility, and cost competitiveness of an enterprise's abilities (Shen, 2007). The primary objective of this paper is to integrate supply chain management with the idea of data envelopment analysis to integrate an efficient supply chain. The proposed model tries to determine the optimum locations of factors and inventories to increase the efficiency of the total system and minimizes total costs. The following summarizes the parameters used in the proposed study.

Parameters

I	Set of customers
J	Set of distribution centers
K	Set of factories
L	Set of products
R	Set of raw materials
V	Set of suppliers
N	Set of output indices

h	Set of input indices
c'_j	Fixed annual setup cost of opening a storage facility *j*
c''_k	Fixed annual setup cost of opening a factory *k*
v'_{jl}	Holding cost of one unit of product *l* in facility *j*
v_{lk}	Production cost of one unit of product *l* in facility *j*
t_{vkr}	Unit cost of transportation and the purchase of raw material *r* from supplier *v* to plant *k*
t'_{ijkl}	Unit cost of product *l* shipped from factory *k* to warehouse *j* and from warehouse *j* to customer *i*
a_{il}	Demand for product *i* for customer *l*
w_j	Throughput of distributer (warehouse) *j*
D_k	Capacity of factory *k*
S_{vr}	Capacity of supplier *v* to provide raw material *r*
u'_{rl}	Rate of raw material *r* in product *l*
u_l	Utilization rate of one unit production *l* from the capacity of the factory
u''_l	Rate of consumption of product l from supplier's throughput
W	Maximum number of allowable warehouses for establishment
P	Maximum number of allowable factories for establishment
O_{nj}	The amount of n^{th} output for inventory *j*
I_{hj}	The amount of h^{th} output for inventory *j*

Decision variables

z_j	A binary variable, which is one if a warehouse is established on location *j* and zero, otherwise
p_k	A binary variable, which is one if a factory is established on location *j* and zero, otherwise
y_{ij}	A binary variable, which is one if warehouse *j* supplies customer *i* and zero, otherwise
q_{vkr}	The amount of raw material *r* shipped from warehouse *v* to factory *k*
q'_{ijkl}	The amount of product *l* shipped from factory *k* to customer *i* using warehouse *j*
$x_{lk} = \sum_i \sum_j q'_{ijkl}$	The amount of product *l* produced in factory *k*
$1 - d_j$	Total harmonic output of warehouse *j*
f_{jh}	Weighted coefficient of input *h* for warehouse *j*
g_{jn}	Weighted coefficient of output *n* for warehouse *j*

The preliminary model of this paper is written based on a combination of the works by Jayaraman and Pirkul (2001) and Altiparmak et al. (2009). The model considers the supply chain consists of four layers, supplier, manufacturer, warehouse (wholesale) and the client. The primary objective of this paper is to locate the factories and warehouses and it determines the amount of order from each supplier. The production plan in this model is limited to single stage, it is also a forward operation and no product is recycled. All parameters are available and there is no uncertainty on any parameters. The capacities of all factors are limited and finally there is a fixed setup cost and a variable cost associated with production of each unit. The mathematical model is as follows,

$$\min z_1 = \sum_j c'_j z_j + \sum_i \sum_j \sum_l v'_{jl} a_{il} y_{ij} + \sum_k c''_k p_k + \sum_i \sum_j \sum_l \sum_k v_{lk}\, q'_{ijkl} + \sum_v \sum_k \sum_r t_{vkr} q_{vkr} + \sum_i \sum_l \sum_k \sum_j t'_{ijkl} q'_{ijkl} \tag{1}$$

subject to

$$\sum_j y_{ij} = 1 \qquad \forall i \tag{2}$$

$$\sum_i \sum_l u''_l a_{il} y_{ij} \le w_j z_j \qquad \forall j \tag{3}$$

$$\sum_j z_j \le W \tag{4}$$

$$\sum_k q_{vkr} \le S_{vr} \qquad \forall v, r \tag{5}$$

$$\sum_i \sum_j \sum_l u'_{rl} q'_{ijkl} \le \sum_v q_{vkr} \qquad \forall k, r \tag{6}$$

$$\sum_i \sum_j \sum_l u''_l q'_{ijkl} \le D_k p_k \qquad \forall k \tag{7}$$

$$\sum_k q'_{ijkl} = a_{il} y_{ij} \qquad \forall i, j, l \tag{8}$$

$$\sum_k p_k \le P \tag{9}$$

$$z_j = \{0,1\} \qquad \forall j \tag{10}$$

$$p_k = \{0,1\} \qquad \forall k \tag{11}$$

$$y_{ij} = \{0,1\} \qquad \forall i, j \tag{12}$$

$$q_{vkr} \ge 0 \qquad \forall v, k, r \tag{13}$$

$$q'_{ijkl} \ge 0 \qquad \forall i, j, k, l \tag{14}$$

Eq. (2) is associated with allocation of warehouse to customer. Eq. (3) determines the capacity of warehouse. Eq. (4) determines the capacity of producer of raw material. Eq. (5) shows the capacity of production of raw materials. According to Eq. (6), the amount of raw materials sent to each factory must be greater than its needs. Eq. (7) demonstrates the capacity of each producer. Eq. (8) explains that the amount of products shipped from different factories to warehouses must meet customers' demands. Eq. (9) determines the maximum number of producers and the other constraints determine the type of variables.

Measuring the relative efficiency of similar units plays essential role for productivity improvement and there are literally various methods to measure the efficiency of similar units such as data envelopment analysis (DEA) (Charnes et al., 1978). Porembski et al. (2005), for instance, presented an application of DEA for various branches of a German bank. Klimberg and Ratick (2008) developed and examined location modeling formulations, which utilize characteristics of the DEA efficiency measure to determine optimal and efficient facility location/allocation patterns. The proposed study of this paper uses the same idea and the mathematical model named SDEA is as follows,

$$\max z = \sum_{r} (1 - d_r) \tag{15}$$

$$\sum_{i=1}^{I} v_{ri} I_{ir} = 1 \qquad \forall r \tag{16}$$

$$\sum_{j=1}^{J} u_{rj} O_{jr} + d_r = 1 \qquad \forall r \tag{17}$$

$$\sum_{j=1}^{J} u_{rj} O_{jk} - \sum_{i=1}^{I} v_{ri} I_{ik} \le 0 \qquad \forall r, \forall k, k \ne r \tag{18}$$

$$v_{ri}, u_{rj} \ge \varepsilon \quad \forall j, i, r \tag{19}$$

$$d_r \ge 0 \qquad \forall r \tag{20}$$

where O_{jr} and V_{rj} are the j^{th} output and input of unit r, and v_{ri} and u_{rj} are the weight variables of the output and input parameters. Now, we present a mathematical model, which uses the idea of SDEA with the preliminary model earlier stated.

$$\max z_1 = \sum_{j=1}^{J} (1 - d_j) \tag{21}$$

$$\begin{aligned} \min z_2 = {} & \sum_{j} c'_j z_j + \sum_{i} \sum_{j} \sum_{l} v'_{jl} a_{il} y_{ij} + \sum_{k} c''_k p_k + \sum_{i} \sum_{j} \sum_{l} \sum_{k} v_{lk}\, q'_{ijkl} \\ & + \sum_{v} \sum_{k} \sum_{r} t_{vkr} q_{vkr} + \sum_{i} \sum_{l} \sum_{k} \sum_{j} t'_{ijkl} q'_{ijkl} \end{aligned} \tag{22}$$

subject to

$$\sum_{j} y_{ij} = 1 \qquad \forall i \tag{23}$$

$$\sum_{i} \sum_{l} u''_l a_{il} y_{ij} \le w_j z_j \qquad \forall j \tag{24}$$

$$\sum_{j} z_j \leq W \tag{25}$$

$$\sum_{k} q_{vkr} \leq S_{vr} \qquad \forall v, r \tag{26}$$

$$\sum_{i}\sum_{j}\sum_{l} u'_{rl} q'_{ijkl} \leq \sum_{v} q_{vkr} \qquad \forall k, r \tag{27}$$

$$\sum_{i}\sum_{j}\sum_{l} u''_{l} q'_{ijkl} \leq D_k p_k \qquad \forall k \tag{28}$$

$$\sum_{k} q'_{ijkl} = a_{il} y_{ij} \qquad \forall i, j, l \tag{29}$$

$$\sum_{k} p_k \leq P \tag{30}$$

$$\sum_{h} f_{jh} I_{hj} = z_j \qquad \forall j \tag{31}$$

$$\sum_{n} g_{jn} O_{nj} + d_j = z_j \qquad \forall j \tag{32}$$

$$\sum_{n} g_{jn} O_{nt} - \sum_{h} f_{jh} I_{ht} \leq 0 \qquad \forall j: \forall t: (j \neq t) \tag{33}$$

$$g_{jn} \geq \varepsilon z_j \qquad \forall j, n \tag{34}$$

$$f_{jh} \geq \varepsilon z_j \qquad \forall j, h \tag{35}$$

$$d_j \geq 0 \qquad \forall j \tag{36}$$

$$z_j = \{0,1\} \qquad \forall j \tag{37}$$

$$p_k = \{0,1\} \qquad \forall k \tag{38}$$

$$y_{ij} = \{0,1\} \qquad \forall i, j \tag{39}$$

$$q_{vkr} \geq 0 \qquad \forall v, k, r \tag{40}$$

$$q'_{ijkl} \geq 0 \qquad \forall i, j, k, l \tag{41}$$

$$g_{jn} \geq 0 \qquad \forall j, n \tag{42}$$

$$f_{jh} \geq 0 \qquad \forall j, h \tag{43}$$

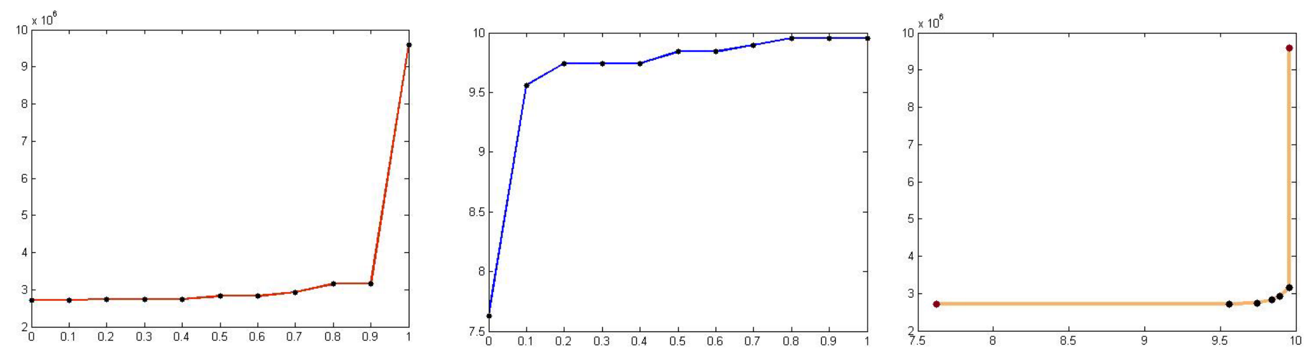
In this model, there two objective functions, where the first one maximizes the efficiency and the second one minimize the cost of supply chain management.

3. Numerical example

In this section, we present the implementation of the proposed study using a numerical example where the input parameters are given as follows, Parameters

I	10
J	10
K	10
L	2
R	2
V	5
N	3
h	4
c'_j	U[10000,30000]
c''_k	U[10000,30000]
v'_{jl}	U[1,10]
v_{lk}	U[1,10]
t_{vkr}	Euclidian norm⁎1
t'_{ijkl}	Euclidian norm⁎1
a_{il}	U[10,100]
w_j	$U[0.17\sum_i \sum_l u''_l a_{il}, 0.5 \sum_i \sum_l u''_l a_{il}]$
D_k	$U[0.17\sum_i \sum_l u_l a_{il}, 0.5 \sum_i \sum_l u_l a_{il}]$
S_{vr}	$u[0.17\sum_i \sum_l u'_{rl} a_{il}, 0.5 \sum_i \sum_l u'_{rl} a_{il}]$
u'_{rl}	U[2,5]
u_l	U[2,5]
u''_l	U[2,5]
W	5
P	5
O_{nj}	U[40,100]
I_{hj}	U[50,100]

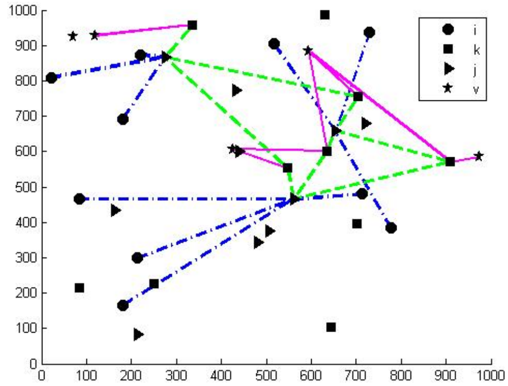
Since there are two objective functions, we consider two objectives by applying a linear combination of two using a parameter α. We also scale the first objective function by multiplying it by 10^6 to scale it into appropriate range. Fig.1 demonstrates the changes of the objective functions when α changes in different range.



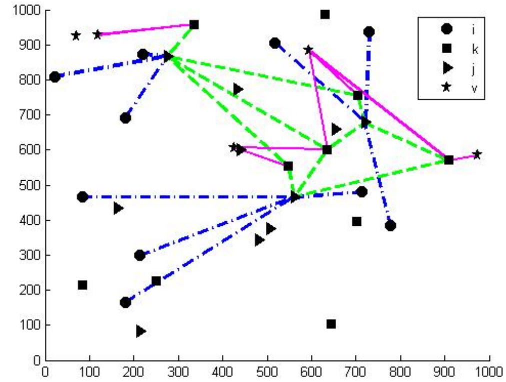
Costs Efficiency Pareto solutions

Fig. 1. The changes on the objective function and Pareto solutions

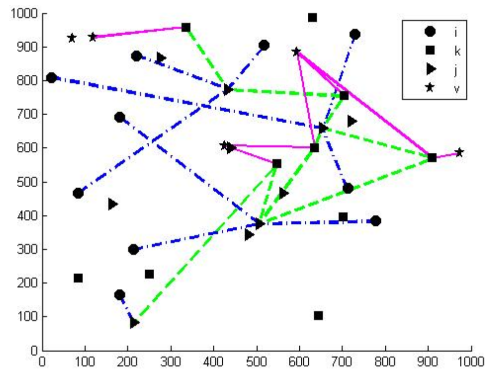
One interesting observation is that when we increase the relative importance of efficiency, the optimal cost will not increase. This means that we may increase the overall efficiency of supply chain without any need to increase the expenses. Fig. 2 demonstrates the location of suppliers under various circumstances.



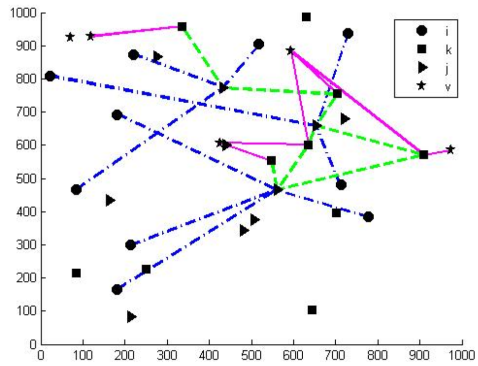
Locations of suppliers when the efficiency is set to 0, 0.1



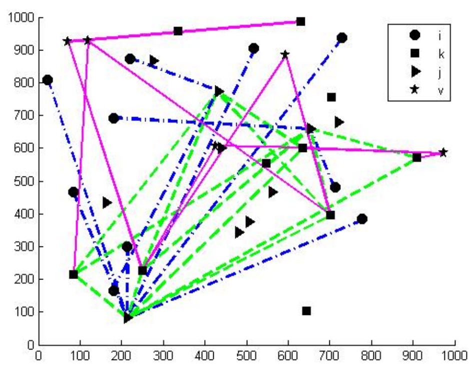
Locations of suppliers when the efficiency is set to 0 and 1



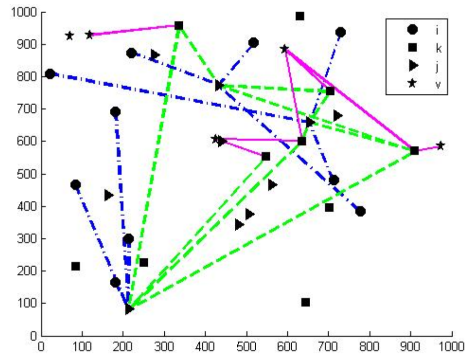
Locations of suppliers when the efficiency is set to 0.7



Locations of suppliers when the efficiency is set to 0.5 and 0.6



Locations of suppliers when the efficiency is set to 1



Locations of suppliers when the efficiency is set to 0.8 and 0.9

Fig. 2. The locations of suppliers under various efficiencies

4. Discussion and conclusion

In this paper, we have presented a supply chain management by considering efficiency in the system. The proposed study considered two objective functions where the first one maximized the efficiency of the supply chain and the second one minimized the cost of facility layout as well as production. The study has been formulated as a mixed integer programming and the implementation of the proposed model has been demonstrated using some numerical example. The preliminary results indicate that it was possible to increase the efficiency of supply chain without increase the supply chain expenses.

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