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Optimizing multi-objective dynamic facility location decisions within green distribution network design

Hamid Afshari [a,]*, Masoud Sharafi [a], Tarek ElMekkawy [b], Qingjin Peng [a]

[a] *Department of Mechanical Engineering, University of Manitoba, Winnipeg, Canada*
[b] *Department of Mechanical and Industrial Engineering, Qatar University, Doha, Qatar*

* Corresponding author. Tel.: +1-204-8694069; *E-mail address:* afsharih@myumanitoba.ca

Abstract

Despite the surge of sustainable economic development which inspires corporations to optimize investment on environmental-friendly infrastructural facilities, limited pragmatic evidences are observed in product-service networks. The importance of such optimized decisions would be highlighted where various stakeholders' objectives are involved in network design. This paper addresses the joint study of optimization for profitability, customer satisfaction, and sustainability by optimizing facility location decisions in distribution-service network with forward and reverse streams. The contribution is minimizing establishment, transportation and inventory management costs and simultaneously maximizing customer satisfaction with sustainable perspective. The presented model is the optimum approach for multi-objective, multi-period, multi-commodity, distribution-service system. The applicability of the proposed model is validated by a real case study. Provided solution proved that a green distribution-service network will increase the efficiency in terms of profitability and customer satisfaction.

Keywords: Dynamic optimization; Facility location; Green distribution network; Mathematical modeling

1. Introduction

Green supply chain management has gained interests among researchers and practitioners as a strategy of the sustainable supply chain management. Srivastava [1] defined the green supply chain management using integrated environmental thinking into supply chain, including product design, material selection, manufacturing processes, delivery of the product to the consumers, and the end-of-life management of the product after its useful life. In another point of view, the logistical activities such as freight transport, storage, inventory management, and materials handling are coordinated to meet customer requirements at the minimum cost. In the past, cost has been defined as internal expenditure for activities within logistics. Increasing attention to the environment makes corporations to take the external costs of logistics into account including: climate change, air pollution, noise, vibration and accidents [2]. This new framework obliges organizations to revise their logistics in order to minimize external costs to achieve social, economic, and environmental objectives.

Different strategies for greening logistics network can be applied that vary from comprehensive strategy of integrating forward and reverse logistics networks to simple strategies of reworking or recycling. Recently, reverse logistics has received the considerable attention due to potentials of value recovery from the used products [3-6]. In such case the reverse logistics is integrated with supply chain, it is called a closed loop supply chain. The focus on reverse logistics is on waste management, material recovery (recycling), parts recovery or product recovery (through remanufacturing). The cost of recovered products can be reduced by optimal

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locations and allocations of facilities in reverse logistics [7, 8]. To highlight the recent contributions in this field, literature is reviewed in next section.

2. Literature review

2.1. Facility location and green logistics

Location-allocation decisions have a large effect on the establishment, transportation, and total cost of logistics. Environmental concerns have recently received the considerable attention in facility location. Li et al. [9] propose a bi-objective model to optimize distribution center locations by minimizing transportation cost and transportation/ production carbon emissions. Mallidis et al. [10] present a multi-objective model to evaluate the effects of different scenarios such as distribution network locations, outsourcing transportation and warehousing operations on environment. The multi-objective optimization model is proposed by Wang et al. [11] for the supply chain network design considers cost of transportation, handling, and green technology acquisition. They measure the CO_2 emissions produced by production and distribution facilities. Diabat and Simchi-Levi [12] suggest a mixed integer programing model for supply chain design with limitation of produced CO_2 in facilities. They prove that the supply chain cost would increase if they put more limitation on produced CO_2. Harris et al. [13] consider transportation cost and CO_2 emissions for optimizing European automobile industry. Chaabane et al. [14] propose a mixed-integer linear programming based model for sustainable supply chain design with the consideration of life cycle assessment principles and material balance constraints at each node of supply chain.

2.2. Product recovery and disposal collection

Some products still have values after consumption; therefore, reverse logistics is applied to exploit this values and reduce possible side effects of disposals. It consists of collecting discarded goods, inspecting and sorting them, followed by some recovery actions, which can either be a simple cleaning or a complex disassembly, and finally a remanufacturing process and a remarketing of the output [15]. Regardless of debates on transportation cost of collecting used materials and possible pollution of recovery sites, reverse logistics and close supply chain management are considered to be environmentally friendly [16]. Linton and Klassen [17], and Srivastava [1] propose models to deal with environmental impacts in the close loop supply chain management. They consider units returned as environmental impact index. Alumur *et al.* [18] propose a profit maximization modeling framework for multi-period reverse logistics network design problems. The model is flexible to incorporate most of the reverse network structures; as case study, it is used for reverse logistics network design for washing machines and tumble dryers in Germany.

In this paper, a multi-objective mixed integer programing model to optimize the location of facilities is presented. Contribution in this research is to integrate forward distribution network and reverse collection and recycling network in order to locate facilities for multiple products. The presented model is for multi-period with deterministic demand. The model can minimize establishment, transportation, inventory management, and recollection of products while maximizing customer satisfaction in dynamic facility location to design the green distribution network.

The rest of the paper is as follows: The model description is presented in section 3. Mathematical model is introduced in section 4. Section 5 presents the case study where the model is implemented, and the conclusion is provided in section 6.

3. Model description

The model is provided for a distribution network with 2 layers for central warehouses, regional warehouses, and customers. The product is sent from central warehouse to regional warehouse and then distributed to users based on their requests. The recycling equipment is established in regional warehouse to recover used materials. These used materials are collected from customers after use. There are some assumptions in the model including:

- The demand of customer is deterministic that can vary over time horizon (in each period).
- Collecting and recovering used materials and waste disposal is considered as the environmental friendly resolution.
- The capacity of each regional warehouse and central warehouse is flexible.

Other characteristics and specifications of the model such as the objective function, constraints, and parameters are explained in the mathematical model section.

4. Model formulation

The sets, indices, and variables embedded in the mixed integer model are introduced in this section:

4.1. Sets and indices

L	Set of central warehouses $(\lvert L\rvert = l, k \in L)$
M	Set of regional warehouses $(\lvert M\rvert = m, j \in M)$
N	Set of customers $(\lvert N\rvert = n, i \in N)$
O	Set of good types $(\lvert O\rvert = o, t \in O)$
F	Set of periods $(\lvert F\rvert = f, p \in F)$

4.2. Variables

$$u_j = \begin{cases} 1, & \text{If a regional warehouse is located in potential point } j, \\ 0, & \text{Otherwise.} \end{cases}$$

$$v_k = \begin{cases} 1, & \text{If a central warehouse is located in potential point } k, \\ 0, & \text{Otherwise.} \end{cases}$$

x_{pjit} Percentage of demand of customer *i* for commodity *t* that is supplied by regional warehouse *j* in period *p*.

y_{pkjt} Percentage of demand of regional warehouse *j* for commodity *t* that is supplied by central warehouse *k* in period *p*.

4.3. Parameters

a_{pit}	Demand of customer *i* for commodity *t* in period *p*,
b_{pjt}	Demand (capacity) of regional warehouse *j* for commodity *t* in period *p*,
c	Cost of transportation per unit,
d_{ij}	Distance between regional warehouse *j* and customer *i*,
d'_{jk}	Distance between regional warehouse *j* and central warehouse *k*,
e_{pkt}	Capacity of central warehouse *k* for commodity *t* in period *p*,
α	Weight of first objective function,
β	Minimum level of customer satisfaction,
q_k	Cost of installation central warehouse *k*,
w_j	Cost of installation regional warehouse *j*,
h_w	Warehousing cost per unit goods in warehouses,
h_s	Warehousing cost per unit goods in stocks,
π	Back ordered cost per unit goods,
g	Percentage of extra part selling after recant,
s'	Amount of parts which is allowed for recant,
w'_j	Cost of establishing of recovery sites,
g'	Percentage of parts which can be sent for recycling,

4.4. Mathematical modeling

$$\begin{aligned}\min z_1 = &\sum_p\sum_j\sum_i\sum_t c \times d_{ij} \times a_{pit} \times x_{pjit} \times (1+g \cdot s')\\ &+\sum_p\sum_k\sum_j\sum_t c \times d'_{jk} \times b_{pjt} \times y_{pkjt}\\ &+\sum_p\sum_j\sum_i\sum_t c \times d_{ij} \times g' \times a_{pit} \times x_{pjit} \times (1+g \cdot s')\\ &+\sum_p\sum_j h_w \times (\sum_k\sum_t b_{pjt} \times y_{pkjt} - \sum_i\sum_t x_{pjit} \times a_{pit} \times (1+g \cdot s'))\\ &+\sum_p h_s \times (\sum_k\sum_t e_{pkt} - \sum_k\sum_j\sum_t y_{pkjt} \times b_{pjt})\\ &+\sum_{p,t} \pi \times (\sum_i a_{pit} - \sum_{i,j} a_{pit} \times (x_{pjit} + g \cdot s'))\\ &+\sum_j (w_j + w'_j) \times u_j\\ &+\sum_k q_k \times v_k \end{aligned} \quad (1)$$

$$\max z_2 = \sum_p\sum_j\sum_i\sum_t (x_{pjit} + g \cdot s')/(n.o.f) \quad (2)$$

Subject to:

$$\sum_j x_{pjit} \le 1 \quad (3)$$

$$\sum_k\sum_t b_{pjt} \ge \sum_i\sum_t a_{pit} \times x_{pjit} \times (1+g \cdot s') \quad \text{for } p=1 \quad (4.1)$$

$$\begin{aligned}&\sum_k\sum_i\sum_t b_{pjt} + (b_{p-1,jt} - (a_{p-1,it} \times x_{p-1,jit} \times (1+g \cdot s'))\\ &\ge \sum_i\sum_t a_{pit} \times x_{pjit} \times (1+g \cdot s') +\\ &a_{p-1,it} \times (1 - x_{p-1,jit}(1+g \cdot s')) \quad \text{for } p>1\end{aligned} \quad (4.2)$$

$$\begin{aligned}&\sum_k\sum_t b_{pjt} \times y_{pkjt} - \sum_i\sum_t a_{pit} \times x_{pjit} \times (1+g \cdot s')\\ &\le \sum_t b_{pjt} \quad \text{for } p=1\end{aligned} \quad (5.1)$$

$$\begin{aligned}&\sum_k\sum_i\sum_t b_{pjt} \times y_{pkjt} + b_{p-1,jt} \times y_{p-1,kjt} -\\ &\sum_i\sum_t (a_{pit} \times x_{pjit} + a_{p-1,it} \times x_{p-1,jit}) \times (1+g \cdot s') -\\ &(a_{p-1,it} \times (1 - x_{p-1,jit}(1+g \cdot s')))\\ &\le \sum_t b_{pjt} \quad \text{for } p>1\end{aligned} \quad (5.2)$$

$$\sum_p\sum_i x_{pjit} \le n \cdot o \cdot u_j \quad (6)$$

$$\sum_j x_{pjit} \ge \beta \quad (7)$$

$$\sum_k y_{pkjt} \le 2 \quad (8)$$

$$\sum_t y_{pkjt} \le m \cdot o \cdot v_k \quad (9)$$

$$\sum_j\sum_t b_{pjt} \times y_{pkjt} \le \sum_t e_{pkt} \quad \text{for } p=1 \quad (10.1)$$

$$\begin{aligned}&\sum_j\sum_t b_{pjt} \times y_{pkjt} - (\sum_t e_{p-i,kt} - \sum_j\sum_t b_{pjt} \times y_{pkjt})\\ &\le \sum_t e_{pkt} \quad \text{for } p>1\end{aligned} \quad (10.2)$$

$$e_{pkt} \times v_k \ge \sum_j b_{pjt} \times y_{pkjt} \quad (11)$$

$$\sum_t b_{pjt} - \sum_i\sum_t a_{pit} \times x_{pjit}(1+g \cdot s') \ge 0 \quad (12)$$

$$x_{pjit} \ge 0 \quad (13)$$

$$y_{pkjt} \ge 0 \quad (14)$$

$$u_j \in \{0,1\} \quad (15)$$

$$v_k \in \{0,1\} \quad (16)$$

In this model, first objective function (Z_1) is to minimize the total cost of transportation, establishment, and inventory management. Z_1 is multiplied by α as the weight of objective function. The second objective function (Z_2) is to maximize customer satisfaction and is multiplied by (1- α).

Constraint (3) indicates that the total percentage of supplied products t from different regional warehouses *j* for each customer *k* in period *p* must be less than demand. In constraint (4), (5), and (12) the capacity of each regional warehouse is defined to cover the demand of customers. Constraint (6) obliges to supply demands from the open regional warehouse and so do constraint (9) for central warehouses. Constraint (7) specifies the minimum level of customer satisfaction for each set of *p* period, *i* customer, and *t* product group. Constraint (8) has the same function of constraint (3) but for central warehouse. The right hand side is defined as 2 to allow the capacity of each regional warehouse *j* to be as much as required for supplying customers. Constraint (10) and (11) refer to the capacity of central warehouses. Constraint (13) to (16) are related to mathematical and integer programming.

5. Case study

In order to verify the proposed model, the model is tested with data from a project to redesign a distribution network in automobile parts distribution. The value of sets, indices, and parameters of the model is shown in Table 1.

Table 1. Values of sets, indices and parameters in studied case.

Sets, indices and parameters	Symbol	Value
Number of customers	*i*	28
Number of candidate regional warehouses	*j*	8
Number of candidate central warehouses	*k*	2
Number of commodities	*o*	5
Number of periods	*p*	4
Rate of recycling	*g'*	0.4
Allowed return of OEM parts	*s'*	0.1
Rate of extra selling after recant	*g*	0.2

In this case, customers are allowed to recant some of the parts that are not used so far due to the low rate of use or any deficiency of quality. This is considered as a policy to increase customer satisfaction and to enhance the service rate of customers. Type of the network is an after sales network to serve warrantee operations of customers. Based on data mining techniques through sold parts, rate of warrantee services that obliges parts to be collected is defined as 40% of distributed parts in a forward logistic operation.

One of the tested scenarios is the feasibility of establishing second central warehouse to better serving of regional warehouses than so far.

The reasons to redesign the current network are as follows:

- All parts are distributed from central warehouse to all customers across the country and again collected to send back; therefore, the cost of transportation is considerably high.
- Increasing competition among manufacturers, brought customers more alternatives for replacing the commodities of company with that of rivals, so the market of company is threatened.
- In case of the commodities that are exclusively distributed by company, the customer satisfaction index is decreased due to lengthy supplying time.

One of the strategies to be applied by management is to revise the current network; redesigning the current network by applying the model is proposed.

The model was coded in LINGO 8 software. The coded model was solved by a Dual Core 2 processor, 1 MB RAM at a reasonable time less than maximum 30 seconds for each run. Although the facility location problem is known as NP-Hard, the software could solve the model by exact method and global optimum was achieved due to type of modeling. Table 2 illustrates the solution with different weights of objective functions and minimum customer satisfaction values.

Table 2. Objective function values versus variety of α and β.

β		α 0.0	0.3	0.5	0.8	1.0
0.2	Z_1	3.28E+10	1.71E+10	1.61E+10	1.44E+10	1.34E+10
	Z_2	1.000	0.997	0.977	0.886	0.389
	Z	-1.000	-0.562	-0.274	0.130	0.356
0.5	Z_1	3.28E+10	1.71E+10	1.65E+10	1.56E+10	1.49E+10
	Z_2	1.000	0.997	0.986	0.927	0.661
	Z	-1.000	-0.561	-0.273	0.147	0.397
0.8	Z_1	3.26E+10	1.73E+10	1.70E+10	1.67E+10	1.64E+10
	Z_2	1.000	0.999	0.992	0.977	0.873
	Z	-1.000	-0.561	-0.270	0.160	0.437

To check the accuracy of the software outcomes, the first and the second objective function is illustrated in Fig.1 and Fig.2 for minimum customer satisfaction of 0.7.

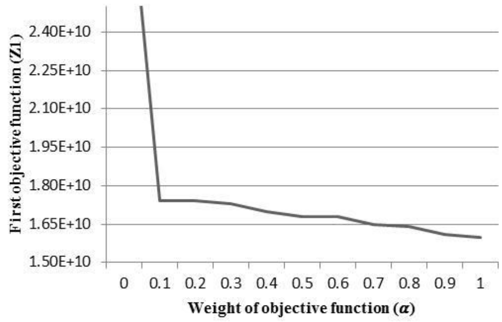

Fig. 1. Fist objective function vale (Z_1) at different α level; the value of Z_1 (total cost) decreases as α increases.

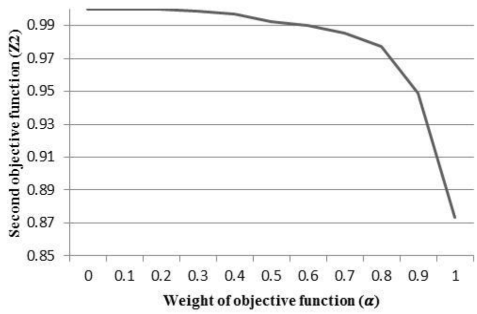

Fig. 2. Second objective function vale (Z_2) at different α level; the value of Z_2 (customer satisfaction) decreases as α increases.

The next step in solving the model is seeking optimum value among different pairs of (α, β). A heuristic method to unite both objective functions is proposed. The method starts with calculation of new function which is the summation of dissatisfaction and cost in percentage. The objective is to minimize this new function. At each β level defined by the manager, we can propose the best alpha and finally optimum values and variables. Fig. 3 depicts new objective function value to select minimum value.

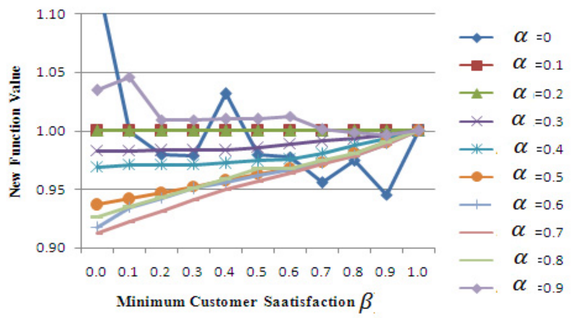

Fig. 3. New objective function at different β level for all series of α levels

According to this method, if manager decides to supply at least 60% of the customer demand, the best adjusting weight coefficient is α =0.7. Applying this method, we can obtain the optimum values as shown in Table 3.

Table 3. Optimum values at α =0.7 and β =0.6.

Metrics	Value
Cost *(Z_1)*	1.62E10
Customer Satisfaction *(Z_2)*	96.7%
Central Warehouses, *v(1,2)*	(1,1)
Regional warehouses, *u(1,2, 3, 4, 5, 6, 7, 8)*	(1,0,1,1,0,1,0,1)

The optimum value of customer satisfaction within the proposed model is compared to that of before implementing the model. Fig.4 illustrates the improvement as 48.77%.

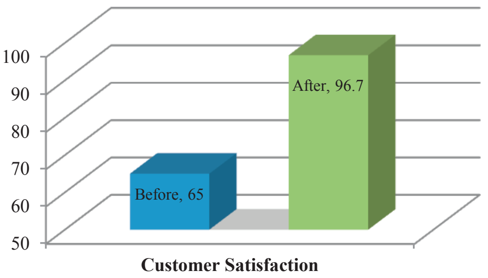

Fig. 4. Customer satisfaction index before and after implementing the suggested model

The main feature of the model is dealing with environmental impact which is supposed to impose high cost and reduce customer satisfaction. On contrary, Table 4 indicates improvement in different metrics by applying green model.

Table 4. Comparison of forward and green logistics optimum values at α =0.7 and β =0.6.

Metrics	*g'*=0	*g'*=0.4	Improvement (%)
Customer Satisfaction *(Z_2)*	96.1%	96.7%	0.6
Total Transportation Cost	1.274E10	1.093E10	14.2
Revenue	1.483E13	1.531E13	3.2
Profit	1.482E13	1.529E13	3.2

This is an important achievement which is proved that establishing green logistics network is more valuable for society, economy, and environment.

6. Conclusion

Application of green logistics to formulate real problems provides great opportunities for all stakeholders. The studied case was a proof of satisfaction for customer, increase market share for company, and benefits for society who are out of our logistics network.

In this research, we presented a green multi objective, multi commodity, multi period location model and solved it with LINGO software. The outputs of model present a trustworthy solution for a green facility location establishment. We believe in the contribution of research that green distribution network is more economic, environment friendly with more social benefits.

Future research in this field is suggested as dealing with uncertainty in supply chain and logistics network. Stochastic programing and robust planning are just some techniques that can be incorporated with proposed model in this research. Reliability studies in supply chain are spreading and facility location within distribution network design is a good venue for application of reliability research.

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