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A MULTI-OBJECTIVE MODEL FOR DECISION MAKING IN A CLOSED-LOOP SUPPLY CHAIN NETWORK

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─Abstract ─

Due to the increased environmental concern and also attain competitive advantages, closed-loop supply chain network design has spurred an interest throughout the two last decades among researchers. In addition, supplier selection and considering importance value of customers are of basis issues, which strongly affect on the supply chain performance. In this study, we propose a closed-loop supply chain network that incorporates the network design decisions in both forward and reverse supply chain networks as well as assimilates strategic and tactical decisions. The network is considered for the production of one product through an assembly of multi modules supplied by different suppliers and usage rate. To solve the proposed model, we use STEP method as an interactive approach which reveals the effect on the network solution due to changes in DM's preferences on various objectives.

Key Words: *Closed-loop Supply Chain Network Design, Supplier selection, STEP method*

JEL Classification: M Business and Management

1. INTRODUCTION

In recent years, the intensity of competition in the market, lead companies to focus on the supply chain and integrated logistics. The design of a closed-loop supply chain network (CSCN), including both forward and reverse flows, has attracted particular attention among researches because of its beneficial business factors. Configuration of supply chain networks, including design for structural, informational and organizational systems, is one of the most important strategic decisions. Usually, the supply chain network design in both forward and reverse flows addresses the number of facilities, their location and capacities and the quantity of flow between them (Fleischmann et al,2004). In many cases, logistics networks are only designed for forward logistics activities without considering the reverse flow of return products. The configuration of both forward and reverse SCN, however, has an intense effect on the performance of each other and also avoid the sub-optimal resulted from separated design (Pishvaee et al,2009:28).

In addition, supplier selection is a critical issue concerned in the process of managing global supply chains (Vinodh et al,2011:38). It can result in better and more efficient services/products and totally can influence the SCN. If a process is done correctly, a higher quality and longer lasting relationship are more attainable. Many papers have considered supplier selection as an important multiple criteria decision making (MCDM) problem in supply chain management. The analytical hierarchy process (AHP) method introduced by Saaty (1980) has many applications in the supplier selection process and many researchers (Kokangu et al,2008:33) utilized the AHP with a multi-objective programming for solving supplier selection problem.

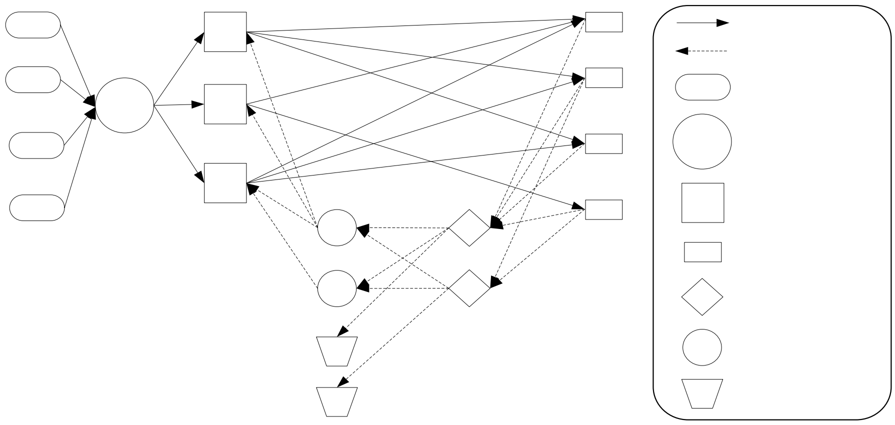
Based on aforementioned considerations, this paper proposes a multi-objective model for a closed-loop supply chain network design. The major issues of the model are as follows: (1) It synthesizes multi-objective decision making (MODM) and multi-attribute decision making (MADM) simultaneously and interactively to obtain DM's preferences by the different compromise solutions proposed, (2) integrates the network design decisions in both forward and reverse supply chain networks as well as incorporate the tactical decisions (e.g., material flows and vehicle type) with strategic ones (e.g., facility location) at each period, to avert sub-optimality resulting from separated design, (3) considers production of one product through an assembly of various components supplied by various suppliers and different usage rate and (5) weight value of customer zones.

2. PROBLEM DEFINITION

The closed-loop supply chain considered in this paper is a multi-stage network, containing assemble, distribution, customer zone, collection, recovery and disposal centers which integrates the network design decisions in both forward and reverse flows. As illustrated in Fig.1, the raw materials and components are shipped to the plant in forward flows. Then, final products assembled by plant are packaged and shipped to distribution centers. In real world situations, customer zones may have different importance values, and those with higher importance, should be satisfied sooner. Thus, demands at the customer zones are met through various distribution centers and vehicles by considering their preferences. In the reverse side, the returned products in the first place are collected in collection centers. After quality testing and disassembly activities, the recoverable products are shipped to recovery facilities and scraped products are shipped to recycling centers. The recovered products are inserted in the forward supply chain network and redistributed to the customer zones. Supply chain network in this paper has a general structure. Proposed network supports recovery and recycling activities and hence can be applied in different industries (Pishvaee and Torabi,2010:161).

Decision horizon in the proposed model includes multi periods. As a result flow quantities between each facility belonging to different echelons are determined according to demand, capacity, cost and other periodic-based parameters at each period. This approach enables us to integrate the tactical decision such as selection of vehicle type or material flow decisions with the strategic level decision like location of facilities (see (Shen,2007:3)).

Fig-1: The Structure of Closed-Loop Supply Chain in the Studied Network



3. MODEL FORMULATION

In this section, a closed-loop supply chain network design model is proposed. It involves three objective functions: (1) minimization of the total costs, (2) maximization of suppliers' ranks and (3) minimization of total delivery time of products (by considering importance value and demand of each customer zone). A number of studies have also taken into account similar objectives (e.g., (Torabi and Hassini,2008:159, Selama et al,2007:159, Pishvaee and Torabi,2010:161)). Different notations used for the model are given below.

Indices:

S	suppliers ($s = 1, \ldots, S$)
R	resources and components ($r = 1, \ldots, R$)
J	candidate location for distribution centers ($j = 1, \ldots, J$)
K	fixed location of customer zones ($k = 1, \ldots, K$)
L	candidate location for collection centers ($l = 1, \ldots, L$)
m	fixed location for recovery centers ($m = 1, \ldots, M$)
N	fixed location for recycling centers ($n = 1, \ldots, N$)
vv	vehicle types (vv = 1, …, *VV*)
T	time periods ($t = 1, \ldots, T$)

Parameters:

d_{kt}	demand of customer zone *k* at period *t*
ct_s	fixed cost of treaty ratification to supplier *s*
f_j	fixed cost of opening distribution center *j*
g_l	fixed cost of opening collection center *l*
b_m	fixed cost of opening recovery center *m*
aa_n	fixed cost of opening recycling center *j*
cx_s	transportation cost per product unit from supplier *s* to assembler
co_j	transportation cost per product unit from supplier *s* to assembler
cu_{jk}^{vv}	transportation cost per product unit from distribution center *j*, to customer zone *k* by vehicle type *vv*
cq_{kl}	transportation cost per unit of returned products from customer zone *k* to collection center *l*
cr_{lm}	transportation cost per unit of returned products from collection center *l* to recovery center *m*
$cs_{\ln}$	transportation cost per unit of scraped products from collection center *l* to recycling center *n*
ch_{mj}	transportation cost per unit of recovered products from recovery center *m* to distribution center *j*
sp_{sr}	Processing cost per unit of product *r* at supplier *s*
ap	Processing cost per unit of product at assembler
dp_j	Processing cost per unit of product at distribution center *j*

cp_l	Processing cost per unit of product at collection center *l*
rp_m	recovery cost per unit of product at recovery center *m*
pp_s	maximum capacity of supplier *s* allocated for product *p* at each period
pa	maximum capacity of assembler *A* allocated for product *p* at each period
pv_j	maximum capacity of distribution center *j* at each period
pvv_{vv}	maximum capacity of vehicle type *vv* at each period
py_l	maximum capacity of collection center *l* at each period
pz_m	maximum capacity of recovery center *m* at each period
pw_n	maximum capacity of recycling center *n* at each period
ts_{sr}	processing time per unit of resource *r* at supplier *s*
ta	processing time per unit of product at assembler
ρ	unit volume of assembled product
rr_{kt}	rate of return percentage from customer zone *k* at period *t*
sf	average scrap fraction at period *t*
sp^{vv}	delivery speed from distribution by vehicle type *vv*
wv_k	weight value of customer zone *k*
ru_r	rate of usage resource *r* at unit product
dis_{jk}	distance between distribution center *j* and customer zone *k*

Variables:

x_{srt}	quantity of resources *r* shipped from supplier *s* to assembler at period *t*
o_{jt}	quantity of products shipped from assembler to distribution center *j* at period *t*
u_{jkt}^{vv}	quantity of products shipped from distribution center *j* to customer zone *k* by vehicle type *vv* at period *t*
q_{klt}	quantity of returned products shipped from customer zone *k* to collection center *l* at period *t*
r_{lmt}	quantity of recoverable products shipped from collection center *l* to recovery center *m* at period *t*
$ss_{\ln t}$	quantity of scrapped products shipped from collection center *l* to recycling center *n* at period *t*
h_{mjt}	quantity of recovered products shipped from recovery center *m* to distribution center *j* at period *t*
rs_s	rank of supplier *s*

$$\sigma_s = \begin{cases} 1 & \text{if supplier s is selected} \\ 0 & \text{Otherwise} \end{cases}$$

$$v_j = \begin{cases} 1 & \text{if a distribution center is opened at location j} \\ 0 & \text{Otherwise} \end{cases}$$

$$y_l = \begin{cases} 1 & \text{if a collection center is opened at location l} \\ 0 & \text{Otherwise} \end{cases}$$

$$z_m = \begin{cases} 1 & \text{if a recovery center is opened at location m} \\ 0 & \text{Otherwise} \end{cases}$$

$$w_n = \begin{cases} 1 & \text{if a recycling center n is opened at location n} \\ 0 & \text{Otherwise} \end{cases}$$

Regarding these notations, the closed-loop supply chain network design is formulated by:

$$\begin{aligned}\min f_1 = &\sum_t \sum_s \sum_r (cx_s + sp_{sr}) x_{srt} + \sum_t \sum_j (co_{Aj} + ap) o_{Ajt} + \sum_t \sum_j \sum_k \sum_{vv} (cu_{jk}^{vv} + dp_j) u_{jkt}^{vv} \\ &+ \sum_t \sum_k \sum_l cq_{kl} q_{klt} + \sum_t \sum_l \sum_n (cs_{\ln} + cp_l) ss_{\ln t} + \sum_t \sum_l \sum_m (cr_{lm} + cp_l) r_{lmt} \\ &+ \sum_t \sum_m \sum_j (ch_{mj} + rp) h_{mjt} + \sum_s ct_s \sigma_s + \sum_j f_j v_j + \sum_l g_l y_l + \sum_m b_m z_m + \sum_n a_n w_n \end{aligned} \quad (1)$$

$$\max f_2 = \sum_s rs_s \sigma_s \quad (2)$$

$$\min f_3 = \sum_t \sum_j \sum_k \sum_{vv} wv_k \frac{u_{jkt}^{vv} \left(\dfrac{dis_{jk}}{sp^{vv}} \right)}{d_{kt}} \quad (3)$$

Subjected to,

$$\sum_r x_{srt} ts_{sr} \le pp_s \quad ;\forall s,t \quad (4)$$

$$\frac{\sum_s x_{srt}}{ru_r} \ge o_{Ajt} \quad ;\forall r,t \quad (5)$$

$$ta(o_{Ajt}) \le pa \quad ;\forall t \quad (6)$$

$$\sum_j \sum_{vv} u_{jkt}^{vv} \ge d_{kt} + \sum_l q_{kl,t-1} \quad ;\forall k,t \quad (11)$$

$$\sum_l q_{klt} \ge rr_{kt} d_{k,t-1} \quad ;\forall k,t \quad (12)$$

$$o_{Ajt} + \sum_m h_{mjt} = \sum_k \sum_{vv} u_{jkt}^{vv} \quad ;\forall j,t \quad (13)$$

$$\rho(o_{Ajt}+\sum_{m}h_{mjt})\le v_j pv_j \quad ;\forall j,t \qquad (7)$$

$$\sum_{k}q_{klt}\le y_l py_l \quad ;\forall l,t \qquad (8)$$

$$\sum_{l}r_{lmt}\le z_m pz_m \quad ;\forall m,t \qquad (9)$$

$$\sum_{l}ss_{lnt}\le w_n pw_n \quad ;\forall n,t \qquad (10)$$

$$sf_t\sum_{k}q_{klt}=\sum_{n}ss_{tnl} \quad ;\forall l,t \qquad (14)$$

$$(1-sf_t)\sum_{k}q_{klt}=\sum_{n}p_{1mt} \quad ;\forall l,t \qquad (15)$$

$$\sum_{m}\sum_{j}h_{mjt}=\sum_{l}\sum_{m}r_{1m,t-1} \quad ;\forall t \qquad (16)$$

$$\sum_{r}x_{srt}\le \sigma_s M \quad ;\forall s,t \qquad (17)$$

$$v_j, y_l, z_m, w_n \in \{0,1\} \quad ;\forall j,l,m,n \qquad (18)$$

$$x_{srt}, o_{Ajt}, u^{vv}_{jkt}, q_{klt}, ss_{lnt}, p_{lmt}, h_{mjt}\ge 0 \quad ;\forall s,r,A,k,j,vv,l,m,n,t \qquad (19)$$

4. IMPLEMENTATION OF THE MODEL

To demonstrate the validity and practicality of the proposed model, a numerical experiment is presented, and results are presented in this Section. To solve the proposed model, among the various algorithms, we applied the progressive search STEP method proposed by Benayoun et al., in this paper; because this method allows a direct comparison between a variety of solutions and also is easier to understand and implement (Steuer,1986). Hence, both objectives are individually optimized and the solutions are arranged in the payoff table. To generate solution for the multi-objective problem, we code all of the mathematical models in GAMS 22.0 and the CPLEX 9.0 solver optimization solver.

Table 1 shows the size of this problem. Capacity data is shown in Table 2. The suppliers are ranked and selected based on the AHP method. The hierarchy structure of supplier selection consists four criteria, namely financial (F), quality (Q), service (S) and extent of fitness (EF), and six suppliers. By using the AHP method, suppliers are ranked and scores calculated as: (Supplier 1= 0.19, Supplier 2= 0.18, Supplier 3= 0.16, Supplier 4= 0.16 , Supplier 5= 0.17, Supplier 6= 0.14).

Table 1: Size of Numerical Experiments.

No. of suppliers	No. of plants	No. of potential distribution centers	No. of customer zones	No. of potential collection centers	No. of potential recovery centers	No. of potential recycling centers	No. of vehicle type	No. of time periods
6	1	6	4	2	2	2	2	4

Table 2: Capacity Data for the Example Network in Each Period.

Suppliers, s=(1-6)	Assembler	Distribution center, l=(1-6)	Vehicle type, vv=(1-2)	Collection center, l = (1-2)	Recovery center, m =(1,2)	Recycling center, n= (1,2)
(800, 1000, 700, 1100, 1000, 1000)	2200	(1000, 700, 300, 800, 800, 1200)	(8000, 5000)	(700, 300)	(900,850)	(300,350)

For the given set of data, the optimal value of cost is obtained as (519,522) and the corresponding composite number for supplier rank and delivery time are as 0.69 and (43.2), respectively. Correspondingly, as shown in Table 3, supplier rank and delivery time objectives are optimized and the composite values obtained.

Table 3: Pay-off table.

Variable	Cost	Supplier rank	Delivery time
Cost	(519,522)	(909,688)	(937,111)
Supplier rank	0.69	1.00	1.00
Delivery time	(43.2)	(40.993)	(14.35)

Based on the obtained optimum values shown in Table 3, weights π_j on objectives

(j=1,2,3) are calculated and subsequently, the first iteration solution using Eqs. (20) and (21) gives the value as $F = (565533, 0.59, 14.35)$.

$$\begin{aligned} &\min : \gamma \\ &\text{s.t.,}\ \ \gamma \geq (f_j^* - f_j(x)).\pi_j,\ \ j = 1,2,...,k \\ &\qquad x \in D^m \\ &\qquad \gamma \geq 0 \end{aligned} \tag{20}$$

$$\pi_j = \frac{\omega_j}{\sum_{j=1}^{k} \omega_j}; \qquad \omega_j = \frac{f_j^* - f_j^{\min}}{f_j^*}\left(\frac{1}{\sqrt{\sum_{i=1}^{k} (c_{ji})^2}}\right),\ \forall j; \quad c_{ji} = c_{ji}^{(3)} - \alpha_j (c_{ji}^{(3)} - c_{ji}^{(2)}), \tag{21}$$

Although the DMs are happy with the composite number of cost and delivery time (these objectives are satisfactory, j□), they are not happy with the solution and tend to choose a higher value of supplier rank (this objectives is unsatisfactory,

j). Hence, for the second iteration, the feasible region of problem is modified as Eq. (22) to incorporate the DMs' preference.

$$S^{m+1} = \begin{cases} S^{m} \\ f_j(x) \geq f_j(x^m) - \Delta f_j, & \text{for some chosen } j \in s \\ f_j(x) \geq f_j(x^m), & j \in u \end{cases} \quad (22)$$

The solution to (22) by $\Delta f_3 = 10$ gives the value $F = (587243, 0.77, 24.35)$ and DMs are happy with the numbers and obtained solution as a non-dominated one. Sensitivity analysis can be done by choosing different values of Δf_j. It is to be noted that if the set of entities or their characteristics of the DMs change, the choice of the SCN can also change. As a result, this type of analysis is more valuable for strategic decision making compared to tactical or operational one.

5. CONCLUSION AND FUTURE RESEARCH

In this paper, a multi-objective model for decision making in a closed-loop supply chain network was studied. The proposed CSCN integrates the network design decisions in both forward and reverse supply chain networks and also incorporates the tactical decisions with strategic ones simultaneously due to prevent sub-optimality caused by the separated design. To adapt the model to real-world conditions, fundamental and logical issues, such as selection of optimal suppliers and importance value of customer zones, which heavily affect to the overall supply chain performance, are considered. Then, to solve the MOMILP model, we applied STEP method. Finally, there are some directions to improve this paper in future research. To match the model to actual conditions, parameters such as demand and cost can be defined in a fuzzy nature. In addition, considering some other tactical decisions and strategic ones is also a valuable research direction.

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