International Journal of Engineering

Journal Homepage: www.ije.ir

An Integrated Closed-loop Supply Chain Configuration Model and Supplier Selection based on Offered Discount Policies

R. Sadeghi Rad, N. Nahavandi*, A. Husseinzadeh Kashan,S. H. Zegordi

Industrial and System Engineering Faculty, Tarbiat Modares University, Tehran, Iran

PAPER INFO

Paper history:
Received 13August2017
Received in revised form 25October2017
Accepted 30November2017

Keywords:
Supplier selection
Closed-loop Supply Chain Network
Loyalty
Discount

ABSTRACT

In this paper, a mathematical programming model is presented for integrated problem of closed loop supply chain network design and supplier selection. The suppliers propose discount policy based on purchase amount and loyalty of buyers which are both taken from the elements of Recency, Frequency and Monetary (RFM) technique. In contrast to the existing closed-loop supply chain network design models which select suppliers based on unit price and quantity discount, the proposed model considers loyalty discount policy along with unit price and quantity discount policy as elements of RFM technique in selecting suppliers. The main objective of this paper which is formulated by a mixed-integer programming model is to minimize the total cost through determining location of facilities, production plan, inventory levels, flows between facilities, transportation type, purchasing amount and selecting best supplier based on a beneficial relationship. Sensitivity analysis is carried out to validate the model and examine the effects of considering discount according to purchase amount and loyalty on the supply chains costs and decisions. Computational results show the effectiveness and usefulness of the model.

***doi**: 10.5829/ije.2018.31.03c.06*

1. INTRODUCTION

In recent years, supply chain management is defined as the process of coordinating, improving and optimizing flows of information, goods, services and money. It is confronted with growing attention in both industry and academia researchers. Supply chain network design (SCND) is one of the significant issues of companies' business strategy and have an influence on efficiency and performance of company for several years [1]. Closed loop supply chain (CLSC) which integrates forward and reverse activities is one of the important subjects of the SCND. Due to environmental regulations, social awareness, customers pressure and economic aspects, the reverse logistic and CLSC have gained notable attention in both industry and academia [2]. In a CLSC, the reverse logistic activities such as collecting used products, inspection and sorting, remanufacturing of recoverable products and disposal of non-recoverable products are considered along with the traditional forward logistic activities [3].

In most companies, a considerable part of product cost is related to the raw material cost [4]. The supplier selection policies are one of the important decisions that companies must integrate it with other strategic decisions. Considering the growing importance of purchasing policy, supplier selection and supplier relation management have become more strategic for companies. Most researches in this field, have investigated supplier selection problem in the forward supply chain and they have paid less attention to this issue in closed loop one [5]. Also, in most models, supplier selection is considered according to the effects of the raw materials unit cost offered by supplier on the supply chain total costs.

Nowadays, suppliers use different techniques in order to persuade buyers to buy more and create long term relationship with them. One of the importance and useful techniques is customer relation management (CRM). CRM is an enterprise approach which is used to understand and impress customer [6]. One of the

*Corresponding Author's Email:*n_nahavandi@modares.ac.ir* (N. Nahavandi)

Please cite this article as: R. Sadeghi Rad, N. Nahavandi, A. Husseinzadeh Kashan,S. H. Zegordi, An Integrated Closed-loop Supply Chain Configuration Model and Supplier Selection based on Offered Discount Policies,International Journal of Engineering (IJE),IJE TRANSACTIONS C: Aspects Vol. 31, No. 3, (March 2018) 184-191

powerful and useful methods used for measuring of the customer relationship strength is RFM technique [7]. RFM is consisted of three elements of Recency (R), Frequency (F) and Monetary (M). Recency indicates the time interval between the time of the latest purchase and the present one. Frequency reflects the number of purchases in a period and monetary shows the total amount of spending in a period. The RFM has been implemented in various industries, such as retail industry, service industry, education industry, health care industry and marketing industry [8].

With regard to the matters enumerated, this paper introduces a new mathematical model for designing a multi-product, multi-stage, multi period and capacitated closed loop supply chain network (CLSCN). The proposed model integrates SCND and supplier selection problem in order to minimize the total cost. In this paper as main contribution, discount policy is formulated according to the quantity discount and loyalty of buyers and the model can hold historical data in order to configure and optimize the CLSCN.

The rest of this paper is organized as follows. Section 2 reviews the related research in the field of CLSC. The model definition is described in section 3 and the mathematical model is stated in section 4. Section 5 discusses computational results and sensitivity analysis of proposed model. In the last section, conclusions of the paper and offered topics for future studies are presented.

2. LITERATURE REVIEW

In this section, the related literature of this paper is briefly reviewed based on two main complementary categories: models which have been developed for the CLSCN design problem and the other ones which have considered supplier selection problem.

The first study in the field of integrated forward/ reverse logistic was performed by Fleischmann et al. [9]. The extension of mentioned study carried out by Salema et al. [10]. Pishvaee and Torabi [11] developed a multi-period, capacitated closed supply chain network model for minimization of the total cost and delivery tardiness under uncertain demands, returns, delivery times, costs and capacities. Subramanian et al. [12]formulated a MILP model for CLSCN design in order to minimize the total cost. Hatefi and Jolai [13] proposed a MILP model for an integrated forward–reverse logistics network design. A multi-objective, multi-stage and single period MILP model developed by Sahraeian et al. [14]. In addition to total cost minimization, they considered CO_2 emission for environment influence as second objective. Fazli-Khalaf and Hamidieh [15] proposed a stochastic MILP model for CLSCN design to minimize supply chain total cost and maximizes social responsibility in an uncertain environment. An integrated forward and reverse supply chain network proposed by Chen et al. [16] in order to minimize the total cost and environmental pollution. Yazdi and Honarvar [17] developed a single-period, single-product, and multi-stage model for integrated CLSCN design and pricing problem. Zohal and Soleimani [18] designed a multi objectives MILP model for CLSC of gold industry. The proposed model developed the ant colony optimization algorithm to minimize the total cost and environment pollution. A multi-objective MILP model developed by Kadambala et al. [19] for maximizing the profits, optimizing customer surplus level and minimizing the energy consumption. Pedram et al. [20] formulated multi-product MILP model for an Iranian tire industry with considering uncertainty in demand, returned products and quality of returned product. Ghomi et al. [2]proposed a single objective mixed integer non-linear programming model. They considered extra inventory and lateral transshipment as resilience strategies in the model to deal with disruption risk.

In the field of supplier selection and SCND, most articles have paid attention to unit price of the suppliers raw materials. Also, a lot of articles have been published in order to select and evaluate suppliers by applying multi criteria decision making method such as analytical hierarchy process (AHP) and TOPSIS which is not the purpose of this article. Thanh et al. [21]developed a multi-stage, multi-product MILP model for forward SCND with deterministic demands. Amin and Zhang [22] addressed supplier selection problem in CLSCN in order to maximize proft and minimize defective rate. In the proposed model unit price, delivery time, and quality of purchased item are considered as important criteria for assessment and selection of them. Govindan et al. [23] developed a multi objective integrated SCND and order allocation problem. To tackle the proposed model, a novel multi-objective hybrid approach has been used. Gholamian and Taghanzadeh [24] formulated MILP model for designing of the wheat supply chain. The proposed model integrated forward supply chain decisions and supplier selection in which suppliers selected according to the proposed unit price of wheat. Mota et al. [25]formulated sustainable CLSCN based on Triple Bottom Line Optimization Modeling. In the proposed MILP model suppliers are selected based on the offered unit price of raw materials. Kamali et al. [26] developed a multi-objectives MINLP model to minimize the total cost through coordination of entire system including a single buyer and multiple vendors. The proposed model which integrates the quantity discount and coordination model for addressing supplier selection issue, has been solved by the particle swarm optimization algorithm and scatter search algorithm. The supplier selection problem in the forward distribution network addressed by Pariazar et al.[27]. In the proposed model, supplier failures and inspection as supplier selection were considered with other supply chain network decision in the uncertain environment. Urata et al. [28] proposed a multi-objectives global supply chain network and supplier selection problem as MILP model. They considered the CO_2 emission and the unit price as important factors for selecting suppliers. Cortinhal et al. [29] developed multi period, multi-product MILP model for CLSCN to minimize the total cost. They executed a computational study on a large size of problem and consider the supplier selection according to unit price of raw materials.

To the best of our knowledge, there are no mathematical model integrated CLSCN design and RFM model as CRM technique. Thus, we proposed a multi-stage, multi-period, multi-product CLSCN and supplier selection problem based on the RFM model which is capable to hold historical data and is offered by suppliers. The objective function of the model consists of the costs of production, recovery of used product, transportation, inventory holding, purchasing and operational costs.

3. PROBLEM DEFINITION

The CLSCN considered in this paper is a multi-echelon, multi-product and multi-period logistics network including suppliers, production/recovery, distribution, collection, disposal centers and customers. The structure of the proposed CLSCN is illustrated in Figure 1.

It is assumed that in the forward flow, suppliers provide raw materials for production centers according to their orders. The products are transferred to the customers via distribution centers in order to satisfy their demands. In the backward flow, the return products are sent to collection centers. The returned products are then categorized into two recyclable and unrecyclable group after inspection. The recyclable products are transferred to production/recovery centers and used as recycled raw materials for production process in these centers. On the other hand, the other ones are sent to disposal centers.

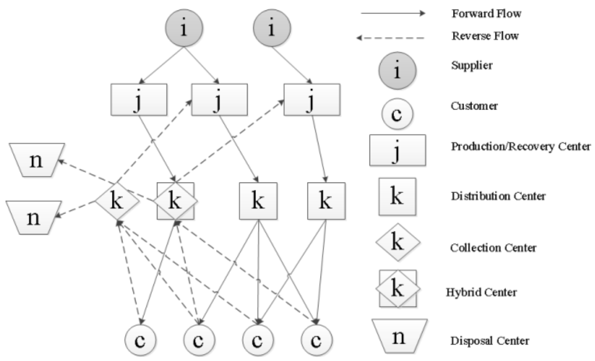

Figure 1. The network structure of the proposed model

The proposed model, which is a single objective problem, attempts to minimize the total cost of the supply chain through determining locations of network facilities, determining the quantity of purchased raw material, produced productions, inventory level at distribution centers and products shipment between the facilities.

To the best of the authors' knowledge, this paper is the first research attempting to integrate the CLSCN design and RFM model.

It has been assumed that the suppliers use RFM model in order to motivate buyers to buy more and as frequent as possible. The production centers, which are considered as customer for suppliers, purchase their required raw materials in order to satisfy their customers demand. In this paper, suppliers propose different and independent discount polices based on purchased amount and customer loyalty.

Considering RFM model to have significant reciprocal benefit for both seller and buyer, it is very important for customer to take an appropriate decision. Thus supply chain decision makers can reduce the total cost according to determination of purchasing amount and purchasing time period or behaving as loyal customer in addition to other supply chain decisions.

It should be noted that the developed model based on RFM technique can be successfully applicable to various industries, such as retail industry, service industry, finance, telecommunication, electronic commerce, etc [8]. In particular, this model can be applied in supply chains in which the suppliers selection based on offered different discount policy is important issue as the other supply chain network design decisions.

4. MODEL FORMULATION

The following sets, parameters and decision variables are used in the proposed model.

Sets:

I	Set of suppliers
J	Set of fixed locations for production/recovery centers
K	Set of possible locations available for distribution , collection and hybrid centers
C	Set of fixed locations of customers
N	Set of fixed locations of disposal centers
V	Set of transportation modes
R	Set of raw materials
P	Set of products
T	Set of time periods in planning horizon
H	Set of discount levels related to purchase amount
Q	Set of discount levels related to loyalty

Parameters:

ocx_k Fixed cost for opening distribution center k

ocy_k Fixed cost for opening collection center k

ocw_k Fixed cost for opening hybrid distribution and collection center k

p_{jpt} Unit production cost of product p at production/recovery center j at time period t

r_{jpt} Unit recovery cost of product p at production/recovery center j at time period t

dis_{kpt} Unit operating cost of product p at distribution center or hybrid processing facility k at time period t

col_{kpt} Unit collection/inspection cost of returned product p at collection center or hybrid processing facility k at time period t

$disp_{npt}$ Unit disposal cost of product p at disposal center n at time period t

inv_{kpt} Unit inventory carrying cost of product p at distribution center or hybrid processing facility k at time period t

s_{jkpvt} Unit transportation cost for product p shipped from production/recovery center j to distribution center or hybrid processing facility k through vehicle v in time period t

s_{kcpvt} Unit transportation cost for product p shipped from distribution center or hybrid processing facility k to customer c through vehicle v in time period t

s_{ckpvt} Unit transportation cost for used product p shipped from customer c to collection center or hybrid processing facility k through vehicle v in time period t

s_{kjpvt} Unit transportation cost for product p shipped from collection center or hybrid processing facility k to production/recovery center j through vehicle v in time period t

s_{knpvt} Unit transportation cost for product p shipped from collection center or hybrid processing facility k to disposal center n k through vehicle v in time period t

rac_{irht} Unit purchasing cost of raw material r from supplier i based on discount level h in time period t

dp_{irqt} Discount rate level q offered by supplier i for raw material r in time period t

pi_{irht} considered purchase amount for including discount level h by supplier i for raw material r in time period t

cpj_{jpt} Production capacity of production/recovery center j for product p in time period t

crj_{jpt} Recovery capacity of production/recovery center j for product p in time period t

cd_{kpt} Holding and operational capacity of distribution center k for product p in time period t

cc_{kpt} Holding and operational capacity of collection center k for product p in time period t

ch_{kpt} holding and operational capacity of hybrid processing facility k for product p in time period t

cdi_{npt} holding and operational capacity of disposal center n for product p in time period t

cp_{irt} Capacity of supplier i for supplying raw material r in time period t

M A sufficient large number

de_{cpt} Demand of customer c for product p in time period t

γ_p Return ratio of used product p

ρ_{rp} Utilization factor of raw material r used in product p

γ_{pr} Utilization factor of recycled raw material used in product p

δ_p Remanufacturing ratio of used product p

α, β A positive number

ε A very small number close to zero

θ Slightly more than ε

Decision variables

QF_{jkpvt} Quantity of finished products p shipped from production/recovery center j to distribution center or hybrid processing facility k through vehicle v in time period t

QF_{kcpvt} Quantity of products p shipped from distribution center or hybrid processing facility k to customer c through vehicle v in time period t

QF_{ckpvt} Quantity of used products p shipped from customer c to collection center or hybrid processing facility k through vehicle v in time period t

QF_{kjpvt} Quantity of recoverable products p shipped from collection center or hybrid processing facility k to production/recovery center j through vehicle v in time period t

QF_{knpvt} Quantity of non- recoverable products p shipped from collection center or hybrid processing facility k to disposal center n through vehicle v in time period t

QS_{ijrht} Quantity of raw material r shipped from supplier i to production/recovery center j according to discount policy according to level h in time period t

I_{kpt} Inventory level of product p at distribution center or hybrid processing facility k at the end of time period t

OX_k Equals to 1 if a distribution center is opened at location k, otherwise 0

OY_k Equals to 1 if a collection center is opened at location k, otherwise 0

OW_k Equals to 1 if a hybrid processing facility is opened at location k, otherwise 0

Z_{irht} Equals to 1 if supplier i gives discount level h for raw material r in time period t, otherwise 0

DP_{irqt} Equals to 1 If supplier i gives discount level q for raw material r in time period t, otherwise 0

S_{irt} Equals to 1 if supplier i is selected for supplying in time period t, otherwise 0

4.1. Mathematical Model

$$
\begin{aligned}
Min\ Z = & \sum_k ocx_k \times OX_k + \sum_k ocw_k \times OY_k + \sum_k ocw_k \times OW_k \\
& + \sum_j \sum_k \sum_p \sum_v \sum_t p_{jpt} \times QF_{jkpvt} + \sum_k \sum_j \sum_p \sum_v \sum_t r_{jpt} \times QF_{kjpvt} \\
& + \sum_k \sum_c \sum_p \sum_v \sum_t dis_{kpt} \times QF_{kcpvt} + \sum_c \sum_k \sum_p \sum_v \sum_t col_{kpt} \times QF_{ckpvt} \\
& + \sum_k \sum_n \sum_p \sum_v \sum_t disp_{npt} \times QF_{knpvt} + \sum_k \sum_p \sum_t inv_{kpt} \times I_{kpt} \\
& + \sum_j \sum_k \sum_p \sum_v \sum_t s_{jkpvt} \times QF_{jkpvt} + \sum_k \sum_c \sum_p \sum_v \sum_t s_{kcpvt} \times QF_{kcpvt} \\
& + \sum_c \sum_k \sum_p \sum_v \sum_t s_{ckpvt} \times QF_{ckpvt} + \sum_k \sum_j \sum_p \sum_v \sum_t s_{kjpvt} \times QF_{kjpvt} \\
& + \sum_k \sum_n \sum_p \sum_v \sum_t s_{knpvt} \times QF_{knpvt} + \sum_i \sum_j \sum_r \sum_h \sum_t rac_{irlt} \times QS_{ijrht} \\
& - \sum_i \sum_j \sum_r \sum_h \sum_q \sum_t rac_{irht} \times dp_{irqt} \times QS_{ijrht} \times DP_{irqt}
\end{aligned} \tag{1}
$$

The objective function (1) aims to minimize the total cost which includes fixed costs for opening distribution, collection/inspection and hybrid centers, production and recovery cost in production/recovery centers, distribution costs of finished products, collection and quality control costs for used product in collection centers, disposal costs for non- recyclable products in disposal centers, inventory holding costs in distribution centers, transportation costs of products between facilities, raw materials purchasing cost from suppliers and cost saving related to discount offered by supplier based on purchasing amount and customer loyalty.

The constraints of the proposed model are expressed in details as follow:

$$\sum_{i}\sum_{l}\sum_{h} QS_{ijrht} + \sum_{k}\sum_{p}\sum_{v} \gamma_{pr} \times QF_{kjpvt} = \sum_{k}\sum_{p}\sum_{v} \rho_{rp} \times QF_{jkpvt} \quad \forall r, j, t \tag{2}$$

$$I_{kpt} = I_{kp(t-1)} + \sum_{j}\sum_{v} QF_{jkpvt} - \sum_{c}\sum_{v} QF_{kcpvt} \quad \forall k, p, t \tag{3}$$

$$\sum_{k}\sum_{v} QF_{kcpvt} = de_{cpt} \quad \forall c, p, t \tag{4}$$

$$\sum_{k}\sum_{v} QF_{ckpvt} = de_{cpt} \times \gamma_p \quad \forall c, p, t \tag{5}$$

$$\sum_{c}\sum_{v} \delta_p \times QF_{ckpvt} = \sum_{j}\sum_{v} QF_{kjpvt} \quad \forall k, p, t \tag{6}$$

$$\sum_{c}\sum_{v} (1-\delta_p) \times QF_{ckpvt} = \sum_{n}\sum_{v} QF_{knpvt} \quad \forall k, p, t \tag{7}$$

$$\sum_{j}\sum_{h} QS_{ijrht} \le cp_{irt} \times S_{irt} \quad \forall i, r, t \tag{8}$$

$$\sum_{k}\sum_{v} QF_{jkpvt} \le cpj_{jpt} \quad \forall j, p, t \tag{9}$$

$$\sum_{k}\sum_{v} QF_{kjpvt} \le crj_{jpt} \quad \forall j, p, t \tag{10}$$

$$I_{kpt} + \sum_{c}\sum_{v} QF_{kcpvt} \le cd_{kpt} \times OX_k + ch_{kpt} \times OW_k \quad \forall k, p, t \tag{11}$$

$$\sum_{c}\sum_{v} QF_{ckpvt} \le cc_{kpt} \times OY_k + ch_{kpt} \times OW_k \quad \forall k, p, t \tag{12}$$

$$\sum_{k}\sum_{v} QF_{knpvt} \le cdi_{npt} \quad \forall n, p, t \tag{13}$$

$$OY_k + OW_k + OU_k \le 1 \quad \forall k \tag{14}$$

Constraint (2) states that the sum of the flows entering each production/recovery center from all suppliers and collection/inspection centers are equal to flow exiting each production/recovery center. Constraint (3) shows the inventory balance limitation in distribution centers for finished products. Constraint (4) guarantees customer demands satisfaction. Constraint (5) represents that the specific ratio of customers' used products are collected by collection/inspection centers. Constrains (6) and (7) show that after inspection and quality checking if collected and used products are recyclable, they will be sent to production/recovery center, otherwise they will be transported to the disposal centers. Constraint (8) shows the maximum capacity of supplier for supplying the raw materials. Constraints (9) and (10) show the capacity of production and recovery in production/recovery center. Constraint (11) shows capacity of distribution center or hybrid processing facility. Constraint (11) states the maximum distribution capacity of each distribution center or hybrid processing facility. Constraint (12) the same as constraint (11), is associated with maximum collecting capacity of each collection/inspection center or hybrid processing facility. Constraint (13) shows the capacity of disposal center. Constraint (14) guarantees that, If needed only one of three distribution center, hybrid processing facility or collection center will be opened at a same potential location.

$$pi_{irlt} \times Z_{irht} \le \sum_{j} QS_{ijrht} \le \left(pi_{ir(h+1)t} - 1\right) \times Z_{irht} \quad \forall\ i, r, h, t \tag{15}$$

$$\sum_{h} Z_{irht} \le 1 \quad \forall\ i, r, t \tag{16}$$

$$\begin{aligned}
&SLC - (\alpha+\beta) \le M \times DP_{ir3t} + \varepsilon \\
&SLC - (\alpha+\beta) \ge M\,(DP_{ir3t} - 1) + \frac{M}{H+1}(DP_{ir1t} + DP_{ir2t}) \\
&SLC - \alpha \le M \times (DP_{ir2t} + DP_{ir3t}) + \varepsilon \\
&SLC - \alpha \ge M\,(DP_{ir2t} - 1) + \frac{M}{H+1}(DP_{ir1t}) \\
&SLC - \beta \le M \times (DP_{ir1t} + DP_{ir2t} + DP_{ir3t}) + \varepsilon \\
&SLC - \beta \ge M\,(DP_{ir1t} - 1) \\
&\forall\ i, r, t
\end{aligned} \tag{17}$$

$$SLC = \alpha \times S_{ir(t-1)} + \beta \times S_{ir(t-2)} + \theta \quad \forall\ i, r, t \tag{18}$$

Constraints (15) and (16) are related to monetary as one of the elements of RFM technique and refer to quantity discount offered by supplier according to purchasing amount.

Constraint (15) guaranties that purchasing amount stays within quantity discount intervals. Constraint (16) states that only one quantity discount level is considered for the purchasing amount.

A set of constraints (17) are pertinent to frequency and recency elements of RFM technique. It is assumed that purchase in each of the two last periods results in benefiting from discount considered for customer loyalty. This assumption refers to frequency element of RFM technique. It should be noted that it is possible to consider more recent periods in the model. The purchasing in the previous period (t-1 period) has more discount in comparison to purchasing in t-2 period. This condition implies the recency element of RFM technique which means that the closer the purchase the more the discount.

For the purpose of modeling customer loyalty in the proposed model, a variable SLC is defined which is the linear combination of supplier selection in the two last periods (Equation (18)) wherein $\alpha > \beta > \theta > \varepsilon > 0$. Therefore, there are four conditions in association with specific supplier in current time period (t) as follow: 1) the supplier has been only selected in time period t-1, 2) the supplier has been selected in time period t-2, 3) the supplier has been selected in both time periods t-1 and t-2. And 4) the supplier has not been selected in both time periods t-1 and t-2. For this reason, binary variable DP_{irqt} is considered for the each of the above mentioned four conditions which indicates that whether the supplier gives loyalty discount level q based on four condition or not. Constraint (17) also guarantee that in each time period, at most only one binary variable DP_{irqt} will be 1 for the specific supplier and the raw material. Generally, the set of above mentioned constraints represent the condition listed in Table 1.

$$QF_{jkpvt}, QF_{kcpvt}, QF_{ckpvt}, QF_{kjpvt}, QF_{knpvt}, QS_{ijrht}, I_{kpt} \geq 0 \quad \forall \ i,j,k,c,n,p,r,v,h,t \tag{19}$$

$$OX_k, OY_k, OW_k, Z_{irht}, DP_{irqt}, S_{irt} \in \{0,1\} \quad \forall \ i,k,r,h,q,t \tag{20}$$

TABLE 1. Condition of supplier selection policy

Condition	
Supplier selection policy	**Activation of related loyalty discount variable**
SLC $< \beta$ $(S_{ir(t-1)} = 0, S_{ir(t-2)} = 0)$	$DP_{ir1t} = 0,\ DP_{ir2t} = 0,\ DP_{ir3t} = 0.$
$\beta \leq$ SLC $< \alpha$ $(S_{ir(t-1)} = 0, S_{ir(t-2)} = 1)$	$DP_{ir1t} = 1,\ DP_{ir2t} = 0,\ DP_{ir3t} = 0.$
$\alpha \leq$ SLC $< \alpha + \beta$ $(S_{ir(t-1)} = 1, S_{ir(t-2)} = 0)$	$DP_{ir1t} = 0,\ DP_{ir2t} = 1,\ DP_{ir3t} = 0.$
$\alpha + \beta \leq$ SLC $(S_{ir(t-1)} = 1, S_{ir(t-2)} = 1)$	$DP_{ir1t} = 0,\ DP_{ir2t} = 0,\ DP_{ir3t} = 1.$

Constraints (19) and (20) enforce the non-negativity and binary conditions of decision variables, respectively.

4.2. Model Linearization As can be seen, the last term of objective function is nonlinear, so that two binary and continuous variables are multiplied to each other. In order to convert nonlinear model to linear one, a novel method developed by Vidal and Goetschalckx [30] is used. According to this method, a new continuous variable is used instead of multiplying two binary and continuous variables. In the last term of objective function, continuous variable QS_{ijrht} is multiplied to binary variable DP_{irqt} . The following Eq. (21) is replaced with nonlinear part of objective function and the set of constraint (22) should be added to the model.

$$\sum_i \sum_j \sum_r \sum_l \sum_u \sum_t rac_{irht} \times dp_{irqt} \times U_{ijrlut} \tag{21}$$

$$\begin{aligned} & U_{ijrlut} \leq M \times DP_{irqt} \\ & U_{ijrlut} \leq QS_{ijrht} \\ & U_{ijrlut} \geq QS_{ijrht} - \left(1 - DP_{irqt}\right) \times M \\ & \forall \ i, j, r, h, q, t \end{aligned} \tag{22}$$

Afterwards, by changing the nonlinear part of objective function with linear one and adding new related set of constraint, the proposed model is converted to linear programming model and can be solved.

5. COMPUTATIONAL EXPERIMNENTS

To appraise validity and performance of the proposed model, the numerical example selected from literature, is solved and the related result are described in this section. The specifications of the test problem are as follow:

$|I| = 2, |J| = 2, |K| = 3, |C| = 4, |N| = 1, |P| = 2, |R| = 2, |H| = 4,$
$|Q| = 4, |V| = 3 \, and \, |T| = 4.$

The parameters of test problem are generated randomly according to the uniform distributions. The model was solved using the CPLEX solver provided via IBM ILOG CPLEX 12.6 on a computer of Intel core i3 3.30 GHz and 4.00 GB of RAM.

5.1. Model Validation To illustrate the validation of the proposed CLSCN design model, sensitivity analysis is carried out on the parameters of the holding cost and the raw material cost. As expected, with increasing raw material cost, the total cost is increased (Table 2). On the other hand, given that the customers demand must be fully satisfied, the total amount of purchased raw materials have not been changed.

TABLE 2. Validation test on the raw materials cost

Test No.	Raw material cost	Supply chain total cost in each period				Supply chain total cost
		1	2	3	4	
1	10	3484658	3499550	3496082	3522874	14,352,184
2	11	3564218	3579450	3575642	3602774	14,671,104
3	12	3643778	3663075	3651602	3682674	14,990,149
4	13	3723338	3739250	3734915	3762426	15,308,949
5	14	3802898	3819150	3814479	3842322	15,627,869

Also, Figure 2 shows that by the holding cost increasing, the total inventory level of finished products in distribution centers are diminished in all time periods. These results reveal the validation of the model.

5. 2. Sensitivity Analysis The inventory level of finished products in distribution centers is analyzed before and after considering only the M element of RFM technique. According to Figure 3, the inventory level is increased in the first time periods and then decrease in inventory level in the last time period is observed. As expected in order to gain the profit of discount, more raw materials are purchased and so the inventory level of finished products is increased in the first time periods.

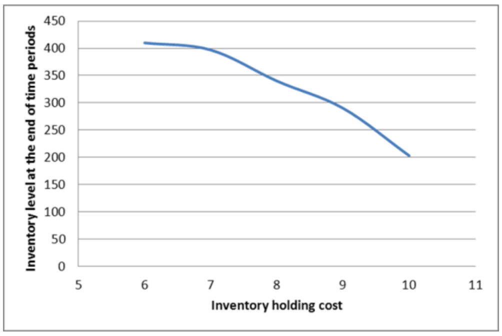

Figure 2. The effect of changing the inventory holding cost on the total inventory level at the distribution centers

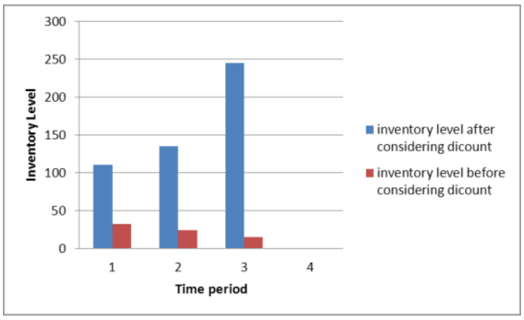

Figure 3. Comparison of inventory level at distribution centers before and after considering discount

In this part, sensitivity analysis of RFM technique are conducted. For this purpose, the effect of considering RFM technique on the total costs, the inventory holding costs and the raw materials purchasing cost is investigated. As it can be seen in Table 3, the raw material purchase cost is significantly decreased after considering discount based on RFM technique. On the other hand, the inventory holding costs in distribution centers are increased by including mentioned discount. The increase in inventory costs is less than the reduction in raw material purchasing cost and hence the total cost is finally dropped by 2.15%.

To analyze the considering of the discount based on the RFM technique, it is assumed that the first supplier proposes discount only for purchasing amount which is related to the M element. The second supplier considers lower discount for purchasing amount in comparison to the first supplier (on average 26% less discount), but on the other hand considers discount for the loyalty as R and F elements of RFM technique.

It is assumed that supplier considers separate discount rate in current time period for purchasing in time period t-1, time period t-2 and both of the mentioned time periods simultaneously. As it can be seen in Figure 4, purchase from the supplier 1 is done only at time period 1, because of considering large discount for purchase amount. On the other hand considering that supplier 2 offers the loyalty discount, purchase from this supplier is done at all time periods and generally, about 87 percent of purchased raw materials are related to the supplier 2.

TABLE 3. Effect of considering discount on supply chain costs

Test condition	Supply chain costs		
	purchasing cost	inventory holding cost	total cost
Regardless of discounts	3,189,200	410	14,352,184
Considering discount	2,877,564	2,940	14,043,108

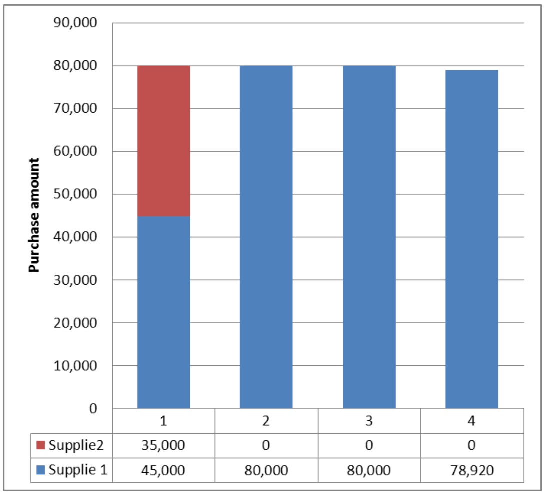

Figure 4. The effects of considering different discount polices on purchase amount from each supplier

Various solutions can be obtained according to the inventory holding costs at distribution centers, discount policies offered by suppliers, customers demand and capacity constraints. Considering discount policy based on the R and the F elements of the RFM technique causes beneficial and loyal relationship with suppliers. This relationship is profitable for both of the suppliers and buyers, so that the buyers gain advantages and attain discount of loyalty and on the other hand sellers preserve their market share and even expand it. Including discount policy based on the M element of the RFM technique results in determining optimal order quantity with regards to trade of supply chain costs such as inventory holding cost and purchasing cost. In general, taking into account the RFM technique in CLSCN leads to reduction of supply chain total costs in comparison to a model wherein the RFM discount policy is not considered. According to the proposed model, supply chain decision makers are capable of choosing best suppliers, intelligently determining how to communicate with them and determining order quantity and other supply chain decisions such as inventory level in distribution centers and transportation modes.

6. CONCLUSION

In this paper, a novel mathematical model is developed for multi-period, multi-stage, multi-product and capacitated a CLSCN to minimize the total cost of the supply chain. Nowadays, the supplier selection problem as strategic decision has significant effects on the performance of supply chains. The suppliers' aim is to create long term and profitable relationships with customers and to this end, they offer different discount policies to persuade buyers to buy more and have long term relationship. Therefore, this paper integrates the CLSCN and supplier selection problem according to discount considered for purchase amount and the loyalty.

To appraise model validation and show its application, some sensitivity analyses were performed by CPLEX. Effects of considering discount policy on supply chain decision were illustrated. Results showed that supply chain decision makers prefer to order in large size and even increase the inventory level in distribution centers in order to benefit from quantity discount. Also, they have created long term relationship with a supplier which considers loyalty discount. Obtained results demonstrate that designing and modeling discount policy based on the RFM technique have significant effect on supply chain total costs reduction (2.15% reduction). The proposed model is able to optimize production plan, transportation mode, inventory levels, flows between facilities, purchase amount and how to behave as loyal customer in order to benefit from offered discount policy for achieving the lowest cost.

Developing exact methods or optimized meta-heuristic algorithm for solving the model in large scale due to high computational time can be a challenging issue for future study. In addition, considering uncertainty in the model parameters can be applied especially in the customers demand and the discount rate to make the model more sustainable and flexible. Also, developing integrated model of pricing problem and proposed model can be proposed as future study.

7. REFERENCES

1. Melo, M.T., Nickel, S. and Saldanha-Da-Gama, F., "Facility location and supply chain management–a review", ***European Journal of Operational Research***, Vol. 196, No. 2, (2009), 401-412.
2. Ghomi-Avili, M., Tavakkoli-Moghaddam, R., Jalali, G. and Jabbarzadeh, A., "A network design model for a resilient closed-loop supply chain with lateral transshipment", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 30, No. 3, (2017), 374-384.
3. Kaya, O. and Urek, B., "A mixed integer nonlinear programming model and heuristic solutions for location, inventory and pricing decisions in a closed loop supply chain", ***Computers & Operations Research***, Vol. 65, (2016), 93-103.
4. Weber, C.A. and Current, J.R., "A multiobjective approach to vendor selection", ***European Journal of Operational Research***, Vol. 68, No. 2, (1993), 173-184.
5. Yan, H., Yu, Z. and Cheng, T.E., "A strategic model for supply chain design with logical constraints: Formulation and solution", ***Computers & Operations Research***, Vol. 30, No. 14, (2003), 2135-2155.
6. Swift, R.S., "Accelerating customer relationships: Using crm and relationship technologies, Prentice Hall Professional, (2001).

7. Schijns, J.M. and Schröder, G.J., "Segment selection by relationship strength", ***Journal of Direct Marketing***, Vol. 10, No. 3, (1996), 69-79.

8. Dursun, A. and Caber, M., "Using data mining techniques for profiling profitable hotel customers: An application of rfm analysis", ***Tourism Management Perspectives***, Vol. 18, (2016), 153-160.

9. Fleischmann, M., Beullens, P., BLOEMHOF-RUWAARD, J.M. and Wassenhove, L.N., "The impact of product recovery on logistics network design", ***Production and Operations Management***, Vol. 10, No. 2, (2001), 156-173.

10. Salema, M.I.G., Barbosa-Povoa, A.P. and Novais, A.Q., "An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty", ***European Journal of Operational Research***, Vol. 179, No. 3, (2007), 1063-1077.

11. Pishvaee, M.S. and Torabi, S.A., "A possibilistic programming approach for closed-loop supply chain network design under uncertainty", ***Fuzzy Sets and Systems***, Vol. 161, No. 20, (2010), 2668-2683.

12. Subramanian, P., Ramkumar, N., Narendran, T. and Ganesh, K., "Prism: Priority based simulated annealing for a closed loop supply chain network design problem", ***Applied Soft Computing***, Vol. 13, No. 2, (2013), 1121-1135.

13. Hatefi, S. and Jolai, F., "Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions", ***Applied Mathematical Modelling***, Vol. 38, No. 9-10, (2014), 2630-2647.

14. Sahraeian, R., Bashiri, M. and Moghadam, A.T., "Capacitated multimodal structure of a green supply chain network considering multiple objectives", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 26, No. 9, (2013), 963-974.

15. Fazli-Khalaf, M. and Hamidieh, A., "A robust reliable forward-reverse supply chain network design model under parameter and disruption uncertainties", ***International Journal of Engineering-Transactions B: Applications***, Vol. 30, No. 8, (2017), 1160-1169.

16. Chen, Y.-W., Wang, L.-C., Wang, A. and Chen, T.-L., "A particle swarm approach for optimizing a multi-stage closed loop supply chain for the solar cell industry", ***Robotics and Computer-Integrated Manufacturing***, Vol. 43, (2017), 111-123.

17. Yazdi, A.A. and Honarvar, M., "A two stage stochastic programming model of the price decision problem in the dual-channel closed-loop supply chain", ***International Journal of Engineering-Transactions B: Applications***, Vol. 28, No. 5, (2015), 738-745.

18. Zohal, M. and Soleimani, H., "Developing an ant colony approach for green closed-loop supply chain network design: A case study in gold industry", ***Journal of Cleaner Production***, Vol. 133, (2016), 314-337.

19. Kadambala, D.K., Subramanian, N., Tiwari, M.K., Abdulrahman, M. and Liu, C., "Closed loop supply chain networks: Designs for energy and time value efficiency", ***International Journal of Production Economics***, Vol. 183, (2017), 382-393.

20. Pedram, A., Yusoff, N.B., Udoncy, O.E., Mahat, A.B., Pedram, P. and Babalola, A., "Integrated forward and reverse supply chain: A tire case study", ***Waste Management***, Vol. 60, (2017), 460-470.

21. Thanh, P.N., Bostel, N. and Péton, O., "A dynamic model for facility location in the design of complex supply chains", ***International Journal of Production Economics***, Vol. 113, No. 2, (2008), 678-693.

22. Amin, S.H. and Zhang, G., "An integrated model for closed-loop supply chain configuration and supplier selection: Multi-objective approach", ***Expert Systems with Applications***, Vol. 39, No. 8, (2012), 6782-6791.

23. Govindan, K., Jafarian, A. and Nourbakhsh, V., "Bi-objective integrating sustainable order allocation and sustainable supply chain network strategic design with stochastic demand using a novel robust hybrid multi-objective metaheuristic", ***Computers & Operations Research***, Vol. 62, (2015), 112-130.

24. Gholamian, M.R. and Taghanzadeh, A.H., "Integrated network design of wheat supply chain: A real case of iran", ***Computers and Electronics in Agriculture***, Vol. 140, (2017), 139-147.

25. Mota, B., Gomes, M.I., Carvalho, A. and Barbosa-Povoa, A.P., "Sustainable supply chains: An integrated modeling approach under uncertainty", ***Omega***, Vol. 77, (2017), 32-57.

26. Kamali, A., Ghomi, S.F. and Jolai, F., "A multi-objective quantity discount and joint optimization model for coordination of a single-buyer multi-vendor supply chain", ***Computers & Mathematics with Applications***, Vol. 62, No. 8, (2011), 3251-3269.

27. Pariazar, M., Root, S. and Sir, M.Y., "Supply chain design considering correlated failures and inspection in pharmaceutical and food supply chains", ***Computers & Industrial Engineering***, Vol. 111, (2017), 123-138.

28. Urata, T., Yamada, T., Itsubo, N. and Inoue, M., "Global supply chain network design and asian analysis with material-based carbon emissions and tax", ***Computers & Industrial Engineering***, Vol. 113, (2017), 779-792.

29. Cortinhal, M., Lopes, M. and Melo, M., "Dynamic design and re-design of multi-echelon, multi-product logistics networks with outsourcing opportunities: A computational study", ***Computers & Industrial Engineering***, Vol. 90, (2015), 118-131.

30. Vidal, C.J. and Goetschalckx, M., "A global supply chain model with transfer pricing and transportation cost allocation", ***European Journal of Operational Research***, Vol. 129, No. 1, (2001), 134-158.

An Integrated Closed-loop Supply Chain Configuration Model and Supplier Selection based on Offered Discount Policies

R. Sadeghi Rad, N. Nahavandi, A. Husseinzadeh Kashan, S. H. Zegordi

Industrial and System Engineering Faculty, Tarbiat Modares University, Tehran, Iran

PAPER INFO

Paper history:
Received 13August 2017
Received in revised form 25October 2017
Accepted 30November 2017

Keywords:
Supplier selection
Closed-loop Supply Chain Network
Loyalty
Discount

چکیده

در این مقاله یک مدل برنامه ریزی ریاضی برای مساله یکپارچه طراحی شبکه زنجیره تامین حلقه بسته و انتخاب تامین کننده ارائه می‌گردد. تامین کنندگان، سیاست تخفیف را بر اساس میزان خرید و وفاداری خریداران درنظر می‌گیرند که این دو سیاست تخفیف بر گرفته از مولفه‌های تکنیک RFM می‌باشد. بر خلاف سایر مدل‌های طراحی شبکه زنجیره تامین حلقه بسته که در انتخاب تامین کننده بیشتر به قیمت واحد مواد و تخفیف مقداری ارائه شده توجه دارند، مدل پیشنهادی سیاست تخفیف مبتنی بر وفاداری را همراه با قیمت واحد مواد خام و تخفیف مقداری، در انتخاب تامین کننده در نظر می-گیرد. هدف این مقاله که به صورت مدل برنامه ریزی عدد صحیح می‌باشد، حداقل سازی هزینه‌های کلی زنجیره تامین از طریق تعیین مکان تسهیلات، برنامه تولید، سطوح موجودی، جریان بین تسهیلات، نوع وسیله حمل و نقل، میزان خرید و انتخاب بهترین تامین کننده بر مبنای ارتباط سودمند می‌باشد. به منظور اعتبارسنجی مدل، تحلیل حساسیت صورت می‌گیرد و بر این اساس تاثیرات در نظر گرفتن تخفیف بر اساس میزان خرید و وفاداری بر هزینه‌ها و تصمیمات زنجیره تامین مورد بررسی قرار می‌گیرد. نتایج محاسباتی کارایی و سودمندی مدل پیشنهادی را نشان می‌دهد.

doi*: 10.5829/ije.2018.31.03c.06*