APEM journal
Advances in Production Engineering & Management
Volume 15 | Number 2 | June 2020 | pp 233–246
https://doi.org/10.14743/apem2020.2.361
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

A closed loop Stackelberg game in multi-product supply chain considering information security: A case study

Babaeinesami, A.[a], **Tohidi, H.**[b,*], **Seyedaliakbar, S.M.**[c]

[a,b,c]Department of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran

ABSTRACT

Realization of information security among supply chain components has always been one of the concerns of supply chain players. This research is the development of a mixed integer mathematical model for solving the problem of designing a multi-product network chain and balancing the separation line of parts in a closed loop supply chain. This model is responsive to market demand for finished products and spare parts simultaneously, and minimizes the transportation costs in forward and backward chains, product purchase costs in assembly section, costs of renewing collected products, and fixed costs of workplaces for the dividing the parts. This game consists of two players: the first player includes: Suppliers, assembly centers, retailers and customers, and the second player includes collection centers, renovation centers, separation centers and disposal centers. The payoff of each actor is minimizing their own objectives, and the objective of the model is the unawareness of the members of the chain from the objectives of other members (information security). The proposed model was solved in GAMS 24 software. Due to the nested model, the first model is solved first and the results of the model are entered into the second model. The results of the model solution show the good performance of the proposed model after implementation for the case study. Among the innovations of this research is the consideration of the Stackelberg game in multi-product closed loop supply chain along with the balance of the separation line of parts with the objective of minimizing all the cost elements.

ARTICLE INFO

Keywords:
Supply chain optimization;
Multi-product supply chain;
Closed-loop supply chain;
Game theory;
Stackelberg game;
Information security;
Renovation of products;
Collection of products

**Corresponding author:*
H_tohidi@azad.ac.ir
(Tohidi, H.)

Article history:
Received 8 May 2019
Revised 7 March 2020
Accepted 17 March 2020

1. Introduction

Over the past few years, the emergence of new technologies and massive changes in world markets have made supply chain management more necessary, in such a way that different organizations have to use supply chain management to create and maintain their competitive position. The information revolution and the emergence of new forms of mutual relationship between organizations and growth of customer expectations with regard to products and services cost, quality, delivery, technology and the committed cycle time, given the increasing competition in global markets and the like, are among the factors that have made organizations around the world to leave traditional purchase systems and move towards the supply chain management system [1].

Due to increased environmental and legal concerns (such as the prohibition of disposal of some products, along with the reduction of raw materials resources and the discovery of the profitable opportunity of recovering returned products), the scope of traditional supply chain management has broadened the introduction of reverse logistics and the closed-loop supply chain [2]. Over the past few decades, many factories have paid particular attention to the retrieval, renewal, and reverse and closed-loop supply chain in a broad-spectrum of products (including steel, tire, printers, ships, disposable cameras, automotive parts, photocopiers, computers and cellphones) and have had a significant improvement in this field [3]. Renovation of the product can be investigated in two respects: the type of returned products or the type of activities. From the first point of view, the return of products may occur for various reasons throughout the life cycle of the product. Commercial returns are the products that customers return to retailers after 30, 60, or 90 days after purchase, requiring a minor fix for re-launch [4].

Generally and traditionally, manufacturers of products and items do not take any responsibility in relation to their goods after distribution and then consumption by consumers, and do not commit to their distributed and consumed products. Today, however, the volume of consumed products has caused significant damage to the environment, and everyone including consumers and authorities are concerned about the environmental conditions. So everyone expects from different manufacturers of goods and items to accept the cost of waste collection resulting from their products, or at least reduce the waste of consumed products [5]. This growing attention towards waste management and the introduction of new rules on waste products (especially in Europe) have led manufacturers to improve their production process, because the cost of disposal and cleaning the environment is very high. The present study seeks to design a multi-product closed loop logistics network [6]. Lessening transportation costs in forward and backward chains, product purchase costs in assembly section, costs of renewing collected products, and fixed costs of workplaces for the dividing the parts is the main goal of companies.

So this research is presented in 8 sections. In the first and second sections, the introduction and literature review are offered. Statement of the problem and the mathematical modeling are presented in the third and fourth section, respectively. The mechanism of the competition between players is reviewed in the fifth section, and the case study in the sixth section. To end with, computational results and conclusions are expressed in seventh and eighth sections, respectively.

2. Literature review

Zailani *et al.* [7] observed the design of the supply chain network, and proposed linear programming based on genetic algorithm. They used linear programming and also genetic operators. They showed that their method with cplex software is more successful than the traditional genetic algorithm. Saidinia *et al.* [8] proposed a nonlinear integer model with solving method of genetic algorithm for designing a reverse network emphasizing on the number and location of return centers with the objective of minimizing costs. They considered the balance between the discount rate of fare and the cost of inventory storage due to the transportation and integration to determine the exact time of integration of the main collection centers. Zhang *et al.* [9] presented an integer linear programming model for planning a supply chain network with stochastic demand and supply. They presented two-stage stochastic optimization approach based on the integer method, which evaluated location decisions and facility allocations in the first stage and the flow routing decisions in the second stage. Kalverkamp *et al.* [10] outlined a reverse logistics network considering two options of renovation, repair and production simultaneously. They showed that considering repair in the reverse logistics system along with re-production can have a great impact on network structure system and costs reduction. Guo *et al.* [11] studied the general supply chain network by formulating and optimizing the robust state of the network using variable non-uniformity theory. Jia *et al.* [12] investigated the design of the reverse logistics network under uncertainty and provided a two-stage probabilistic programming approach in which the solving method was the integrated SA heuristic method.

Sahebjamnia *et al.* [13] proposed a scenario-based stochastic optimization model for designing a supply chain network, in which demand, the number and quality of returns, and all stochastic variables were considered to be stochastic. Uncertainty in the quality of returned products was considered and a mixture of renewable and crushed in return flow were considered as stochastic parameters. Pereira *et al.* [14] presented a multi-objective stochastic two-stage integer model for reverse logistics programming, considering multi-product, technology selection, and the transportation costs and the expansion of waste to be probabilistic. Bhattacharya *et al.* [15] presented an integer programming model for designing of a large-scale paper renovation network under uncertainty. Gu *et al.* [16] developed an integer programming model for simultaneous programming and designed a multi-product multi-cycle closed-loop supply chain in which the given time cycle was divided into strategic time units and these units themselves were divided to smaller parts. They also considered travel time of flows, processing time of facilities, categorization of product materials, product disassembly structure and environmental objectives imposed by law. Hajipour *et al.* [17] projected a strong optimization model for designing a closed-loop supply chain network that supposed the number of refunded products, customer demand, after market, and transportation costs in fluctuating stochastic sets. Hasanov *et al.* [18] studied the design of the reverse supply chain network by designing product components and different levels of quality. They considered the collection of returns from retailers in combination with the renovation of collected product components using the renovation service network. Ruiz-Torres *et al.* [19] provided a reverse supply chain network model that minimized the total cost of return process of electronic products. As'ad *et al.* [20] offered an integer linear programming model for designing a reverse supply chain system for programming the renewal of electronic products in the state of Texas and decreasing the waste flow. Their model measured the obsolescence of electronic products and the multitasking function of resources. Yu *et al.* [21] presented a mathematical model for inventory management in supply chain. They solved the presented mathematical model using Ant colony algorithm. Using fuzzy numbers in model is one of the contributions of model. Orščič *et al.* [22] presented a model for third-party logistics service providers in supply chains. Considering sustainability in green supply chain is one of the contributions of their research. he models incorporates the application of quality measurement standards and a PDCA cycle system of continuous improvement into indicators. Liang *et al.* [23] presented a stochastic mathematical model for remanufacturing in supply chain. Thy proposed the coordination mechanism to describe relationship between supplier and service provider. Finally the adaptive immune genetic algorithm was established to solve the model.

An account of the literature review is given in Table 1.

Table 1 A review of previous research

Author	Network structure	Decision-making factors	Modeling type	Data type	Planning type	Single / multi product	Capacity status	Objective function
Zailani (2019)	CLSC	LA	MIP	Dtr	MP	MC	UnCap	Min cost
Saedinia (2019)	CLSC	LA	MILP	Dtr	SP	SC	UnCap	Min profit
Jing (2019)	RSC	FL	MILP	Dtr	MP	MC/SC	Cap	Min cost
Jia *et al.* (2019)	CLSC	Rou	MIP	Dtr	SP	SC	Cap	Min cost
Ruiz-Torres (2019)	RSC	Flow	MINLP	Stoch	MP	SC	Cap	Min profit
Matthias (2019)	CLSC	Rou	MIP	Stoch	SP	MC	Cap	Min profit
Guo (2019)	CLSC	FL	MINLP	Dtr	SP	SC	UnCap	Min profit
Hajipour *et al.* (2019)	RSC	Allo	MIP	Dtr	SP	MC	Cap	Min cost
As'ad *et al.* (2019)	CLSC	Flow	MILP	Dtr	SP	SC	UnCap	Min cost
Bhattacharya *et al.* (2018)	RSC	FL	MILP	Stoch	MP	MC	Cap	Min cost
Gu *et al.* (2018)	CLSC	Allo	MILP	Dtr	SP	SC	Cap	Min cost
This paper	CLSC	Flow,Allo	MIP	scenario	MP	MC	Cap	Min cost

As the result of the review of previous research shows, the closed-loop supply chain problem has attracted many scholars so far. This attention has been intensified over the last few years due to the importance of economic savings as well as the consideration of environmental aspects and the increasing global attention to sustainable development of organizations. But the issue of multi-product closed-loop supply chain regarding the separation line balance has not been studied so far and is considered as an innovation of this research. Minimizing transportation costs in forward and backward chains, product purchase costs in assembly section, costs of renovating the collected products, costs of customer refunds, collection costs and fixed costs of the workstations for separating the parts are the main objectives of the companies. Accordingly, given the intense competition, the necessity and importance of this research is quite obvious.

3. Statement of the problem

The problem under study in this research is the design of the multi-product closed-loop supply chain, considering the balance of the separation line of parts. In this study, an integrated model that mutually optimizes the strategic and tactical decisions of a multi-product closed loop supply chain is studied. Once defining decision is done, variables and related parameters, the mathematical model of the problem is established. In this problem, strategic level decisions link with programming the flow of products in the direct and reverse supply chain concurrently. Tactical level decisions are on the balance of separation lines of parts in the reverse chain. To reach a viable and competitive closed-loop supply chain network, the separation line of parts and reverse distribution processes should be able to work simultaneously. This research is the development of a mixed integer mathematical model for solving the problem of designing a multi-product network chain and balancing the separation line of parts in a closed-loop supply chain. This model is responsive to market demand for finished products and spare parts simultaneously, and minimizes the transportation costs in forward and backward chains, product purchase costs in assembly section, costs of renovating the collected product, and fixed costs of workstations for separation of parts. The uncertainty considered is a scenario based. In this type of uncertainty the proposed model is executed on the number of scenarios considered. Therefore, the proposed model considers all the scenarios and gives the optimal solution for all the scenarios. It is important to note that different scenarios are likely to occur with deferent possibility. Therefore, this uncertainty makes decisions at the macro and comprehensive level of supply chain.

As shown in Fig. 1, the raw materials are carried from suppliers to assembly centers. Then the products are sent to retailers and eventually to customers. Renewable products move to collection centers. Finally, these products are detracted from the collection centers to disposal and separation centers which the renovated products are directed to the assembly centers.

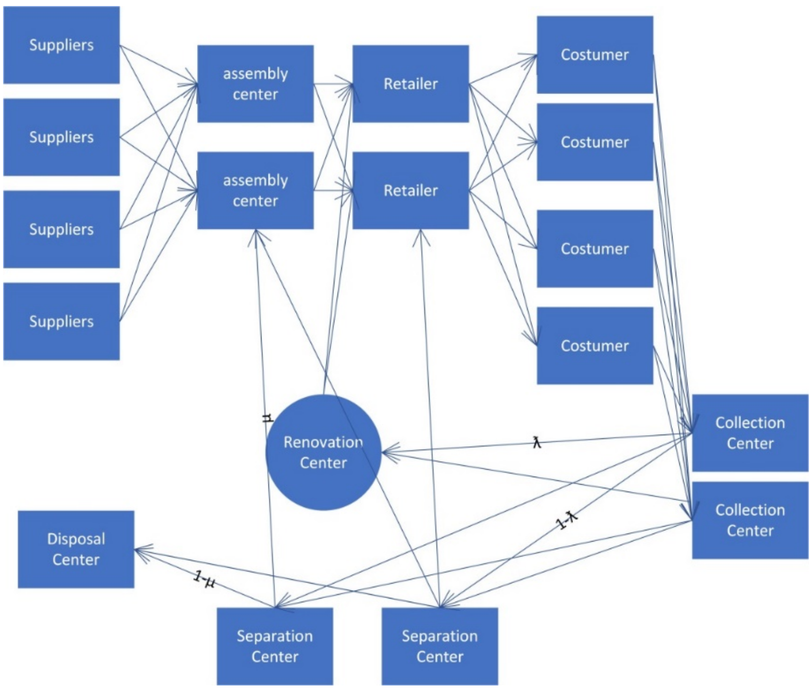

Fig. 1 The flow of products and raw materials in the problem

The main aim of this problem is to estimate the amount of products and parts transported from different centers to each other, as well as allocating and balancing the separation line of parts to minimize system costs.

The innovations of this research are as follows:

- regarding a Stackelberg game in the multi-level multi-product closed loop supply chain and multi-product closed loop,
- considering the balance of the separation line of parts with the objective of minimizing all cost elements,
- developing a model for a multi-product integrated supply chain considering disposal, renovation and collection centers,
- considering scenarios of market recession and boom,
- considering the information security in the supply chain using the game mechanism design.

4. Materials and methods

4.1 Background on the Stackelberg game

In a study on the market economy, Stackelberg used a hierarchical model to describe the market situation for the first time. The model of Stackelberg games is a type of economic games in which the first player initially moves, and then the second player. This model illustrates that there are different decision-makers in the market, and they act according to their own needs which often have different goals but are proportional to the decision of others. Suppose, in the simplest state, there are only two decision makers. So this model models a two-level hierarchy simultaneously, one of them independently managing the market and the other one acting independently (follower). In such games, the first player plays a leading role, and the second player follows the first player. In such games, the follower player observes the move of the leader player and then moves accordingly. Therefore, the best move of the second player is the same move that the Stackelberg balance predicts. A leader can dictate his objectives to the market, but has to wait for the consequences of this decision. The decision of customer determines the profits of the leader.

4.2 Mathematical modeling

Model assumptions are as follows:

- the capacity of all facilities in forward and backward flows is constrained and constant,
- the costs of transportation, purchase, renovation and workstations are definite and pre-identified,
- the rates of collection, disposal, and separation of parts are pre-identified and the amount of renovation is a certain percentage of customer demand and other parameters,
- all workstations can perform operations at the same cost,
- each product is completely separated.

Index

i	Suppliers	p	Index of scenario
j	Assembly centers	c	Index of parts
k	Retailers	g	Index of products
l	Consumers	s	Workstations for separation of parts
m	Collection centers	t	Index of separation operation
r	Renovation centers	a	Index of nodes
d	Separation centers		

Parameters

d_{ij}	Distance between supplier *i* and assembly center *j*
d_{jk}	Distance between assembly center *j* and retailer *k*

d_{kl} Distance between retailer k and consumer l
d_{lm} Distance between consumer l and collection center m
d_{mr} Distance between collection center m and renovation center r
d_{md} Distance between collection center m and separation center d
d_{rk} Distance between renovation center r and retailer k
d_{dj} Distance between separation center d and assembly center j
d_d Distance between separation center d and disposal center
a_{gcip} Capacity of supplier i for part c of product g in scenario p
b_{gip} Capacity of assembly center j for product g in scenario p
c_{gkp} Capacity of retailer k for product g in scenario p
u_{glp} Demand of consumer l for product g in scenario p
e_{gmp} Capacity of collection center m for product g in scenario p
f_{grp} Capacity of renovation center r for product g in scenario p
g_{gcdp} Capacity of separation center d for part c of product g in scenario p
tc Transportation cost
s_{gci} Purchase cost of part c of product g from supplier i
w_{gr} Cost of renovation for product g at center r
cc_{glm} Cost of collection for product g from consumer l to center m
pc_{gcd} Cost of separation for part c of product g at center d
rf_{glm} Cost of refund to customer l for product g to collect to center m
wdc_{gc} Cost of disposal for part c of product g
o Fixed cost of workstation
q_{gc} Number of parts c in product g
θ_{max} Maximum percentage of collected products
θ_{min} Minimum percentage of collected products
γ Percentage of the product sent from collection centers to renovation centers
μ Percentage of parts sent from separation centers to assembly centers
A_a Set of artificial nodes on chart of separation operation
B_t Set of natural nodes on chart of separation operation
d_{B_t} Time of separation operation t
S_{dp} Maximum number of workstations in separation center d in scenario p
w_{time} Working time

Variables

X_{gcijp} Amount of part c of product g sent from supplier i to assembly center j in scenario p
y_{gjkp} Amount of product g sent from assembly center j to retailer k in scenario p
w_{gklp} Amount of product g sent from retailer k to consumer l in scenario p
a_{glmp} Amount of product g sent from consumer l to collection center m in scenario p
b_{gmrp} Amount of product g sent from collection center m to renovation center r in scenario p
s_{gmdp} Amount of product g sent from collection center m to separation center d in scenario p
E_{grkp} Amount of product g sent from renovation center r to retailer l in scenario p
z_{gcdjp} Amount of part c of product g sent from separation center d to assembly center j in scenario p
F_{gcdp} Amount of part c of product g disposed from separation center d in scenario p
T_{gcdp} amount of part c obtained from the separation of product g at separation center d
CT_{dp} Cycle time of separation center d in scenario p
M_{tsdp} 1, If the separation operation t is allocated to workstation s at separation center d in scenario p; otherwise 0
L_{tdp} If the separation operation t is done at separation center d in scenario p.

$$Min z = tc\left(\sum_{g\in G}\sum_{c\in C}\sum_{i\in I}\sum_{j\in J}\sum_{p\in P} x_{gcijp}\cdot d_{ij} + \sum_{g\in G}\sum_{k\in K}\sum_{j\in J}\sum_{p\in P} y_{gjkp}\cdot d_{jk} + \sum_{g\in G}\sum_{k\in K}\sum_{l\in L}\sum_{p\in P} w_{gklp}\cdot d_{kl} + \sum_{g\in G}\sum_{c\in C}\sum_{i\in I}\sum_{j\in J}\sum_{p\in P} x_{gcijp}\cdot s_{gci}\right) \quad (1)$$

$$\sum_{j\epsilon J} x_{gcijp} \le a_{gcip} \qquad \forall g\in G, c\in C, i\in I, p\in P \quad (2)$$

$$\sum_{k\epsilon K} y_{gjkp} \le b_{gip} \qquad \forall g\in G, i\in I, p\in P \quad (3)$$

$$\sum_{l\epsilon L} W_{gklp} \le c_{gkp} \qquad \forall g\in G, k\in K, p\in P \quad (4)$$

$$\sum_{k\epsilon K} W_{gklp} \ge u_{glp} \qquad \forall g\in G, l\in L, p\in P \quad (5)$$

$$\sum_{j\epsilon J} y_{gjkp} + \sum_{r\epsilon R} e_{grkp} - \sum_{l\epsilon L} W_{gklp} = 0 \qquad \forall g\in G, k\in K, j\in J, p\in P \quad (6)$$

Model of the first player

Objective Eq. 1 is the minimization of transportation costs between all facilities of closed-loop supply chain and the cost of purchasing parts from the supplier. Constraint Eq. 2 shows that the total amount of purchased parts from suppliers can't exceed their capacity in each scenario. Constraint Eq. 3 states that the production amount of finished products should not exceed the production capacity of the assembly center in each scenario. Constraint Eq. 4 ensures that the amount of products distributed by the retailer to the consumer can't exceed the distribution capacity of retailer. Constraint Eq. 5 ensures that the demand of all consumers is satisfied. Constraint Eq. 6 ensures that the amount of parts purchased from the supplier and the amount sent from the separation center to the assembly center is equal to the amount of product that was made at the center assembly of these parts and sent to the retailer.

Model of the second player

$$\begin{aligned} Min z = &\sum_{g\in G}\sum_{m\in M}\sum_{l\in L}\sum_{p\in P} A_{glmp}\cdot d_{lm} + \sum_{g\in G}\sum_{m\in M}\sum_{r\in R}\sum_{p\in P} b_{gmrp}\cdot d_{mr} \\ &+ \sum_{g\in G}\sum_{m\in M}\sum_{d\in D}\sum_{p\in P} S_{gmdp}\cdot d_{md} + \sum_{g\in G}\sum_{k\in K}\sum_{r\in R}\sum_{p\in P} e_{grkp}\cdot d_{rk} \\ &+ \sum_{g\in G}\sum_{c\in C}\sum_{d\in D}\sum_{j\in J}\sum_{p\in P} z_{gcdjp}\cdot d_{dj} + \sum_{g\in G}\sum_{c\in C}\sum_{d\in D}\sum_{p\in P} f_{gcdp}\cdot d_{dc} \\ &+ \sum_{g\in G}\sum_{m\in M}\sum_{r\in R}\sum_{p\in P} b_{gmrp}\cdot w_{gr} + \sum_{g\in G}\sum_{m\in M}\sum_{l\in L}\sum_{p\in P} A_{glmp}\cdot rf_{glm} \\ &+ \sum_{g\in G}\sum_{m\in M}\sum_{l\in L}\sum_{p\in P} A_{glmp}\cdot cc_{glm} + \sum_{g\in G}\sum_{c\in C}\sum_{d\in D}\sum_{p\in P} f_{gcdp}\cdot wdc_{gc} \\ &+ \sum_{s\in S}\sum_{d\in D}\sum_{p\in P} N_{sdp}\cdot O_{dp} \end{aligned} \quad (7)$$

$$\sum_{r\epsilon R} b_{gmrp} + \sum_{d\epsilon D} S_{gmdp} \le e_{gmp} \qquad \forall g\in G, m\in M, p\in P \quad (8)$$

$$\sum_{k\epsilon K} E_{grkp} \le f_{grp} \qquad \forall g\in G, r\in R, p\in P \quad (9)$$

$$f_{grp} + \sum_{d \epsilon D} z_{gcdjp} \leq g_{gcdp} \qquad \forall g \in G, c \in C, d \in D, p \in P \qquad (10)$$

$$\sum_{i \epsilon I} x_{gcijp} + \sum_{d \epsilon D} z_{gcdjp} - \sum_{l \epsilon L} y_{gklp} \cdot q_{gc} = 0 \qquad \forall g \in G, k \in K, p \in P \qquad (11)$$

$$\theta_{min} \sum_{k \epsilon K} W_{gklp} \leq \sum_{m \epsilon M} a_{gklp} \leq \theta_{max} \sum_{k \epsilon K} W_{gklp} \qquad \forall g \in G, l \in L, p \in P \qquad (12)$$

$$\gamma \sum_{l \epsilon L} a_{glmp} - \sum_{r \epsilon R} B_{gmrp} = 0 \qquad \forall g \in G, m \in M, p \in P \qquad (13)$$

$$\sum_{m \epsilon M} b_{gmrp} - \sum_{k \epsilon K} e_{grkp} = 0 \qquad \forall g \in G, r \in R, p \in P \qquad (14)$$

$$(1-\gamma) \sum_{l \epsilon L} a_{glmp} - \sum_{d \epsilon D} s_{gmdp} = 0 \qquad \forall g \in G, m \in M, p \in P \qquad (15)$$

$$(1-\mu) \sum_{m \epsilon M} s_{gmdp} \cdot q_{gc} - f_{gcdp} = 0 \qquad \forall g \in G, c \in C, d \in D, p \in P \qquad (16)$$

$$\mu \sum_{m \epsilon M} s_{gmdp} \cdot q_{gc} - \sum_{j \epsilon J} z_{gcdjp} = 0 \qquad \forall g \in G, c \in C, d \in D, p \in P \qquad (17)$$

$$\sum_{B_t \epsilon S(A_a)} L_{tdp} = 1 \qquad \forall a = 0, d \in D, p \in P, \forall t \in T \qquad (18)$$

$$\sum_{B_t \epsilon S(A_a)} L_{tdp} = \sum_{B_t \epsilon P(A_a)} L_{tdp} \qquad \forall a \neq 0, d \in D, p \in P, \forall t \in T \qquad (19)$$

$$\sum_{s \epsilon S} M_{tsdp} = L_{tdp} \qquad \forall t \in T, d \in D, p \in P \qquad (20)$$

$$\sum_{t \epsilon T} M_{tsdp} \cdot d_{B_t} \leq w_{time} / \left(\sum_{j \epsilon J} \sum_{c \in C} z_{gcdjp} + \sum_{c \epsilon C} f_{gcdp} \right) \qquad \forall s \in S, d \in D, p \in P \qquad (21)$$

$$X_{gcijp}, y_{gjkp}, a_{glmp}, b_{gmrp}, s_{gmdp}, e_{grkp}, z_{gcdjp}, f_{gcdp} \geq 0 \qquad (22)$$

$$L_{tsdp}, L_{tdp} \in \{0, 1\} \qquad (23)$$

Objective function Eq. 7 is to minimize transportation between supply chain facilities, renovation costs of collected products, refund costs to the customer for the collection of products, costs of product collection and the cost of disposal of parts.

Constraint Eq. 8 indicates that the amount of products sent from the collection center to the renovation center can't exceed the capacity of the collection center. Constraint Eq. 9 indicates that the amount of products sent to the retailer from the renovation center can't exceed the capacity of the renovation center. Constraint Eq. 10 shows that the amount of parts sent from the separation center to the assembly and disposal center can't exceed the capacity of the separation center. Constraint Eq. 11 shows that the amount of products sent from the assembly center and the amount sent from the renovation center to the retailer is equal to the amount sent from the retailer to the consumer. Constraint Eq. 12 ensures that the amount of products collected from consumers should be between minimum and maximum of collection rates. Constraint Eq. 13 ensures that γ percent of the products collected from consumers is equal to the amount of products sent from the collection center to the renovation center. Constraint Eq. 14 ensures that the amount of products that is renovated in the renovation center is equal to the amount sent to the retailer from that center. Constraint Eq. 15 ensures that the remaining amount of the collected products is sent to the separation centers. Constraint Eq. 16 ensures that the amount of parts that is obtained at the separation center and in unusual conditions is equal to the amount disposed. Constraint Eq. 17 ensures that the remaining amount of parts in the separation center in the usable conditions is equal to the amount sent from the separation center to the assembly center. Constraints Eq. 18 and Eq. 19 ensure that exactly one branch of the part separation graph is selected in each period. Constraint Eq. 20 ensures that each separation operation is exactly assigned to one of the work stations. Constraint Eq. 21 ensures that the time spent on each workstation should not be longer than the cycle time; the cycle time is obtained from dividing the working time into the amount of the separated parts. Constraint Eq. 22 implements the non-negativity constraint on decision variables. Constraint Eq. 23 shows binary variables.

4.3 Competition mechanism of players as Stackelberg game

Realization of information security among supply chain components has always been one of the concerns of supply chain players. Each member of the supply chain is trying to minimize their costs, but none of them are willing to inform other supply chain members of their objective functions and amount of cost minimization. So in this study, using a Stackelberg game, a game is designed to cover these objectives. This game consists of two players: the first player includes: Suppliers, assembly centers, retailers and customers, and the second player includes collection centers, renovation centers, separation centers and disposal centers. The payoff of each actor is minimizing their own objectives, and the objective of the game is the unawareness of the members of the chain from the objectives of other members (information security). Also due to the inherent uncertainty of the mentioned problem, the parameters and decision variables are considered as scenario-based. Therefore, the uncertainty used in this paper is scenario-based. The scenarios considered in this study include three scenarios:

- market recession,
- normal market conditions,
- market boom.

Table 2 shows design of scenarios:

Table 2 Design of scenarios

Scenario	Scenario description	Demand
Scenario1	market recession	Up to 2000
Scenario2	normal market	Up to 1000
Scenario3	market boom	Up to 500

So the designed game mechanism is as shown in Fig. 2.

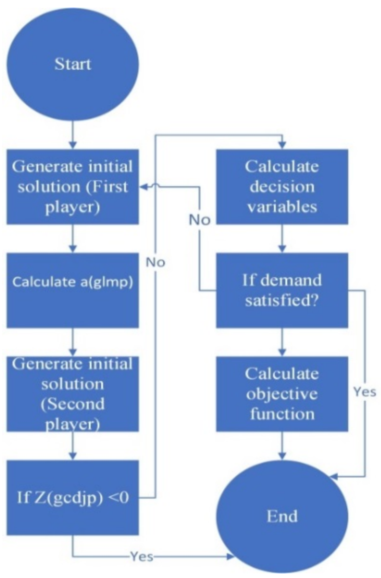

Fig. 2 Designed game mechanism

In order to implement the game mechanism, first, the first model (first player model) will be solved then the value of the variable a_{glmp} will be calculated. This value will enter into the second model, and then the model of the second player will be solved. If the value of z_{gcdjp} is negative, the solving mechanism is complete; otherwise the decision variables of the second model will be solved and if the demand is satisfied, the model is complete; otherwise, the first model will be solved again to satisfy the demand.

5. Results and discussion

5.1 Case study

Simachob company, the largest and only Iranian company in the field of wood industry, is located on an area of 50,000 square meters using the most advanced machinery, the most experienced specialists, employing 320 skilled workers, more than 30 contracting companies, having over half a century of experience in the field of designing and producing various types of park furniture (benches, trash cans and gazebos), park fitness equipment, polyethylene play tools for children, park granule flooring and equipping parks, passages and streets. This company has been investigated for the case study. The factory has 5 suppliers, 3 assembly centers, 6 retailers, 4 collection centers, 3 separation centers, 3 products, 3 renovation centers and 5 major customers.

Below are some of the parameters of the first model.

Table 3 shows the distance between the collection center m and the separation center d. The distances are in meters. For example, the distance between the collection center 3 and the separation center 2 is 8700 meters.

Table 4 shows the demand for the product from customers in different scenarios. As can be seen, the first scenario is market boom, the second scenario is normal conditions and the third scenario is market recession. Thus, according to the following table, the amount of demand for the first product in the third scenario for the fourth customer is 80 units.

Also, some of the parameters of the second model are as follows. For example, the capacity of the renovation center for the product g in the scenario p is given in Table 5. For example, the second product's capacity in the third scenario at the third renovation center is 800 units.

Also, each of the products of this factory consists of three separate parts. Therefore, the cost of disposing part c of product g is shown in Table 6. It should be noted that the costs mentioned are in dollars. For example, the cost of disposing the part 3 of the second product is $ 32.

Table 3 Distance between the collection center and the separation center

m \ d	1	2	3	4
1	2500	6200	1000	4600
2	4100	2600	8700	9600
3	14200	9500	4800	6900

Table 4 Demand for each product by customers in each scenario

g.p \ l	l1	l2	l3	l4	l5
g1.p1	950	860	900	790	880
g1.p2	550	420	450	350	510
g1.p3	120	200	90	80	150
g2.p1	650	710	600	750	790
g2.p2	500	480	530	480	450
g2.p3	230	200	250	300	220
g3.p1	500	550	600	580	560
g3.p2	220	250	260	300	200
g3.p3	100	150	90	120	110

Table 5 The capacity of the renovation center for the product in each scenario

l / g.p	r1	r2	r3
g1.p1	1500	1500	1500
g1.p2	1000	1000	1000
g1.p3	800	800	800
g2.p1	1300	1300	1300
g2.p2	900	900	900
g2.p3	800	800	800
g3.p1	1800	1800	1800
g3.p2	1200	1200	1200
g3.p3	900	900	900

Table 6 Disposal cost for each part of the product

c / g	c1	c2	c3
g1	8	15	23
g2	12	5	32
g3	11	9	30

5.2 Computational results

The problem is solved using the GAMS 24 software. Fig. 3 shows the results of the model's solution in various iterations. As can be seen, in the base model (first model), the amount of costs decreases with increasing the number of iterations. Also, by increasing the number of iterations, the cost of the second model gradually increases, and this trend continues until the costs are almost constant. The reason for the increase in costs in the second model is model's attempt to satisfy demand. In the solution approach, at first, the first model declares the amount of demand to the second model, and since the second model is not able to satisfy demand at first; it therefore tries to satisfy the demand as much as possible. And otherwise it will satisfy the rest of the demand in the next period.

Table 7 shows the amount of products sent from the assembly center to the retailer in each scenario. For example, the amount of products type 1 sent from the second assembly center to the fifth retailer in the first scenario is 628 units. Also, the amount of products type 2 sent from the first assembly center to the sixth retailer in the third scenario is 213 units. Moreover, the analysis of scenarios shows that the amount of products sent in the market boom scenario is much more than the other scenarios.

Fig. 4 shows the comparison of different scenarios in terms of the objective function. As previously mentioned, there are three scenarios including boom, normal conditions and recession in this study. As shown in Fig. 1, scenario 1 (market boom) has higher trend value of the objective function than other scenarios. Also, as expected, the second project is in balance and the objective function in this scenario is in intermediary state. Finally, in the third scenario, which is recession in the market, the objective function has its lowest value compared to the rest of the scenarios. It is natural that, when the market is in recession, the values of objective functions are less than the boom state, since in the event of recession, transportation costs and other costs are greatly reduced.

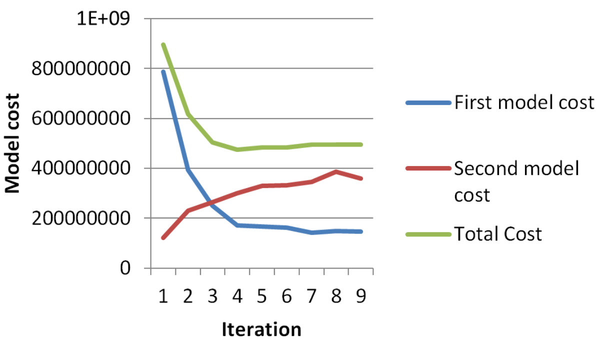

Fig. 3 Results of model solution for different iterations

Table 7 The amount of products sent from the assembly center to the retailer in each scenario

g.j.k	$p = 1$	$p = 2$	$p = 3$
g1.j2.k1	669	371	-
g1.j3.k2	686	368	142
g1.j3.k3	-	323	-
g1.j2.k5	628	-	102
g1.j3.k5	632	-	213
g2.j1.k5	-	323	247
g2.j1.k6	616	-	213
g2.j2.k1	684	-	104
g2.j2.k2	665	339	247
g2.j2.k3	700	322	-
g2.j2.k4	-	382	119
g2.j2.k6	-	338	119
g2.j3.k2	608	-	-
g2.j3.k3	644	302	-
g3.j3.k3	-	301	177
g3.j1.k4	696	-	193
g3.j1.k6	652	363	-
g3.j2.k1	699	321	138
g3.j2.k2	-	333	238
g3.j2.k4	655	-	187
g3.j3.k1	617	331	-
g3.j3.k4	-	302	105
g3.j3.k5	607	-	231

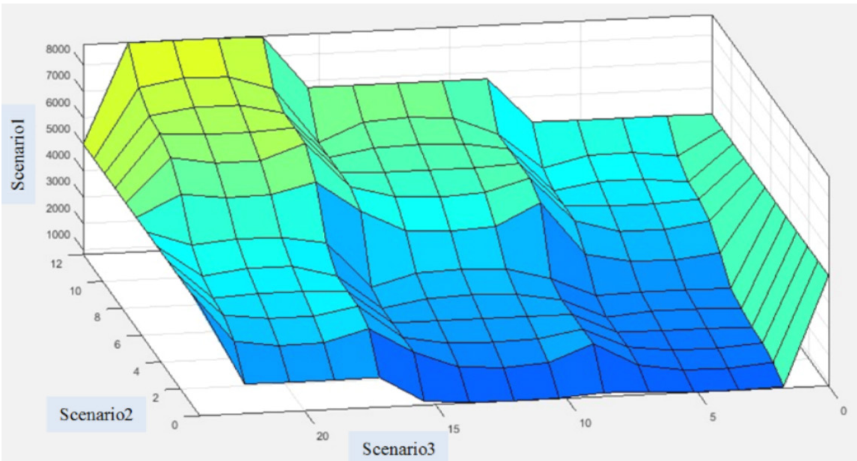

Fig. 4 Comparison of the costs of different scenarios

Sensitivity analysis of mathematical models shows the sensitivity and importance of effective parameters on objective functions and model variables. Here, the effects of changes in demand are examined in two models. As can be seen, with demand increasing, the costs of the first and second models and the total model will increase. According to Fig. 5, a 30 % reduction in demand will result in a cost of 12490000 for the first model and a cost of 29319900 for the second model. An increase of 10 % in demand will lead to an increase in the costs of the first model to 23711000 and an increase in the second model to 34420000. Eventually, an increase in demand up to 30 percent will result in an increase in total costs to 58131000.

Fig. 6 shows the effect of disposal costs on the two models. As can be seen, with the in-crease in disposal costs, the costs of the first and second models and the total model will increase. According to Fig. 4, a 30 % reduction in disposal costs will result in a cost of 31150000 for the second model and a cost of 10374000 for the first model. Also, a 10 % increase in the disposal costs will lead to an increase in the cost of the first model to 18711000 and an increase in the second model to 38950000. Eventually, the increase in the disposal costs up to 30 % will lead to an increase in the costs of the first and second models to 21415000 and 45105000 respectively.

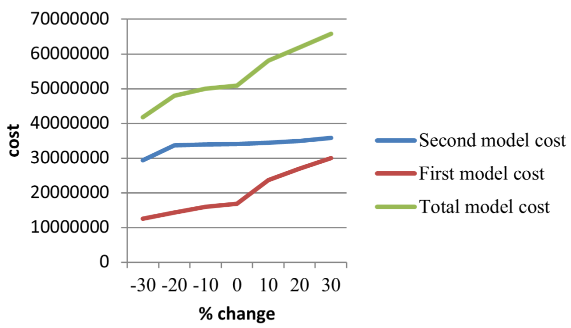

Fig. 5 Sensitivity analysis of the amount of demand

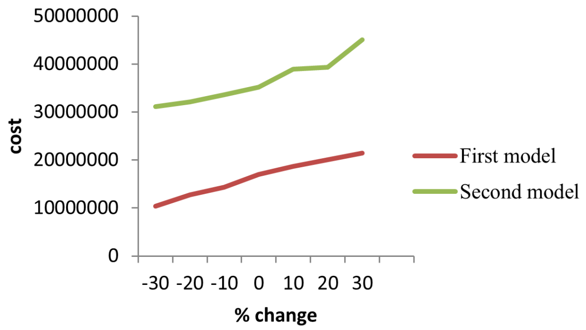

Fig. 6 The effect of disposal costs on two models

The reason for the increase in costs in the second model is the attempt to satisfy demand. In the solution approach, at first, the first model declares demand to the second model; and since the second model is not able to satisfy demand at first, it tries to solve the model with more iterations which increases the amount of costs.

6. Conclusion

Reverse logistics management and closed-loop supply chains are of the important and vital aspects of every business and ensure the production, service distribution, and support of every kind of products. In today's business market, which the life cycle of products shortens every day, product return policies are defined with quick response times and customer service and more emphasis on return management, renovation and re-storage of the finished products. New government laws and green laws that associate with to return and removal of materials also need high-level logistics managers and supply chain processors to concentrate more on the reverse logistics process and the closed-loop supply chain. This survey is the development of a mixed integer mathematical model for solving the problem of designing a multi-product chain network and balancing the separation line of parts in a closed-loop supply chain. This model is responsive to the market demand for finished products and parts simultaneously and minimizes transportation costs in forward and backward chains, product purchase costs in the assembly section, the costs of renovating the products, and fixed cost of workstations for separation of parts. According to the importance of the information, a Stackelberg game including two models is presented. The case study of this research is Simachob, which has 5 suppliers, 3 assembly centers, 6 retailers, 4 collection centers, 3 separation centers, 3 products, 3 renovation centers and 5 major customers. So the amount of problem variables has been computed. For example, the amount of products type 1 sent from the second assembly center to the fifth retailer in the first scenario is 628 units. Also, the amount of products type 2 sent from the first assembly center to the sixth retailer in the third scenario is 213 units. Sensitivity analysis results indicate that a 30 % reduction in demand will result in a cost of 12490000 for the first model and a cost of 29319900 for the second model. An increase of 10 % in demand will lead to an increase in the costs of the first model to 23711000 and an increase in the second model to 34420000. Eventually, an increase in demand up to 30 percent will result in an increase in total costs to 58131000. One of the constraints of this research is the lack of access to accurate cost information. The following are also suggested for future studies:

- Considering other types of uncertainty for example stochastic or fuzzy.
- Considering other games in the closed-loop supply chain, for example Nash equilibrium.
- Solving closed-loop supply chain problem using meta-heuristic approaches such as ant colony algorithm and genetic algorithms.
- Considering the failure rate in disposal centers and separation centers.

References

[1] Li, J., Wang, Z., Jiang, B., Kim, T. (2017). Coordination strategies in a three-echelon reverse supply chain for economic and social benefit, *Applied Mathematical Modelling,* Vol. 49, 599-611, doi: 10.1016/j.apm.2017.04.031.

[2] Kim, J., Chung, B.D., Kang, Y., Jeong, B. (2018). Robust optimization model for closed-loop supply chain planning under reverse logistics flow and demand uncertainty, *Journal of Cleaner Production,* Vol. 196, 1314-1328, doi: 10.1016/j.jclepro.2018.06.157.

[3] Flygansvær, B., Dahlstrom, R., Nygaard, A. (2018). Exploring the pursuit of sustainability in reverse supply chains for electronics, *Journal of Cleaner Production,* Vol. 189, 472-484, doi: 10.1016/j.jclepro.2018.04.014.

[4] Heydari, J., Govindan, K., Sadeghi, R. (2018). Reverse supply chain coordination under stochastic remanufacturing capacity, *International Journal of Production Economics,* Vol. 202, 1-11, doi: 10.1016/j.ijpe.2018.04.024.

[5] Phuc, P.N.K., Yu, V.F., Tsao, Y.-C. (2017). Optimizing fuzzy reverse supply chain for end-of-life vehicles, *Computers & Industrial Engineering,* Vol. 113, 757-765, doi: 10.1016/j.cie.2016.11.007.

[6] Shi, J., Zhou, J., Zhu, Q. (2019). Barriers of a closed-loop cartridge remanufacturing supply chain for urban waste recovery governance in China, *Journal of Cleaner Production,* Vol. 212, 1544-1553, doi: 10.1016/j.jclepro.2018.12.114.

[7] Zailani, S., Iranmanesh, M., Foroughi, B., Kim, K., Hyun, S.S. (2019). Effects of supply chain practices, integration and closed-loop supply chain activities on cost-containment of biodiesel, *Review of Managerial Science*, 1-21, doi: 10.1007/s11846-019-00332-9.

[8] Saedinia, R., Vahdani, B., Etebari, F., Nadjafi, B.A. (2019). Robust gasoline closed loop supply chain design with redistricting, service sharing and intra-district service transfer, *Transportation Research Part E: Logistics and Transportation Review,* Vol. 123, 121-141, doi: 10.1016/j.tre.2019.01.015.

[9] Zhang, Z.-C., Guo, L., Wu, Q.-Q., Gong, L.-M., Ni, T.-T., Guo, P.-H. (2019). Dynamic pricing with reference quality effects in closed-loop supply chain, In: Huang, G., Chien, C.F., Dou, R. (eds), *Proceeding of the 24th International Conference on Industrial Engineering and Engineering Management,* Springer, Singapore, 549-557, doi: 10.1007/978-981-13-3402-3_58.

[10] Kalverkamp, M., Young, S.B. (2019). In support of open-loop supply chains: Expanding the scope of environmental sustainability in reverse supply chains, *Journal of Cleaner Production,* Vol. 214, 573-582, doi: 10.1016/j.jclepro.2019.01.006.

[11] Guo, J., He, L., Gen, M. (2019). Optimal strategies for the closed-loop supply chain with the consideration of supply disruption and subsidy policy, *Computers & Industrial Engineering,* Vol. 128, 886-893, doi: 10.1016/j.cie.2018.10.029.

[12] Jia, F., Gong, Y., Brown, S. (2019). Multi-tier sustainable supply chain management: The role of supply chain leadership, *International Journal of Production Economics*, Vol. 2017, 44-63, doi: 10.1016/j.ijpe.2018.07.022.

[13] Sahebjamnia, N., Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. (2018). Sustainable tire closed-loop supply chain network design: Hybrid metaheuristic algorithms for large-scale networks, *Journal of Cleaner Production,* Vol. 196, 273-296, doi: 10.1016/j.jclepro.2018.05.245.

[14] Pereira, M.M., Machado, R.L., Ignacio Pires, S.R., Pereira Dantas, M.J., Zaluski, P.R., Frazzon, E.M. (2018). Forecasting scrap tires returns in closed-loop supply chains in Brazil, *Journal of Cleaner Production,* Vol. 188, 741-750, doi: 10.1016/j.jclepro.2018.04.026.

[15] Bhattacharya, R., Kaur, A., Amit, R.K. (2018). Price optimization of multi-stage remanufacturing in a closed loop supply chain, *Journal of Cleaner Production,* Vol. 186, 943-962, doi: 10.1016/j.jclepro.2018.02.222.

[16] Gu, X., Ieromonachou, P., Zhou, L., Tseng, M.-L. (2018). Developing pricing strategy to optimise total profits in an electric vehicle battery closed loop supply chain, *Journal of Cleaner Production,* Vol. 203, 376-385, doi: 10.1016/j.jclepro.2018.08.209.

[17] Hajipour, V., Tavana, M., Di Caprio, D., Akhgar, M., Jabbari, Y. (2019). An optimization model for traceable closed-loop supply chain networks, *Applied Mathematical Modelling*, Vol. 71, 673-699, doi: 10.1016/j.apm.2019.03.007.

[18] Hasanov, P., Jaber, M.Y., Tahirov, N. (2019). Four-level closed loop supply chain with remanufacturing, *Applied Mathematical Modelling,* Vol. 66, 141-155, doi: 10.1016/j.apm.2018.08.036.

[19] Ruiz-Torres, A.J., Mahmoodi, F., Ohmori, S. (2019). Joint determination of supplier capacity and returner incentives in a closed-loop supply chain, *Journal of Cleaner Production,* Vol. 215, 1351-1361, doi: 10.1016/j.jclepro.2019.01.146.

[20] As'ad, R., Hariga, M., Alkhatib, O. (2019). Two stage closed loop supply chain models under consignment stock agreement and different procurement strategies, *Applied Mathematical Modelling,* Vol. 65, 164-186, doi: 10.1016/j.apm.2018.08.007.

[21] Yu, W., Hou, G., Xia, P., Li, J. (2019). Supply chain joint inventory management and cost optimization based on ant colony algorithm and fuzzy model, *Tehnički Vjesnik – Technical Gazette,* Vol. 26, No. 6, 1729-1737, doi: 10.17559/TV-20190805123158.

[22] Orščič, J., Rosi, B., Jereb, B. (2019). Measuring sustainable performance among logistic service providers in supply chains, *Tehnički Vjesnik – Technical Gazette*, Vol. 26, No. 5, 1478-1485, doi: 10.17559/TV-20180607112607.

[23] Liang, Y., Qiao, P.L., Luo, Z.Y., Song, L.L. (2016). Constrained stochastic joint replenishment problem with option contracts in spare parts remanufacturing supply chain, *International Journal of Simulation Modelling,* Vol. 15, No. 3, 553-565, doi: 10.2507/IJSIMM15(3)CO13.