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Considering chain to chain competition in forward and reverse logistics of a dynamic and integrated supply chain network design problem

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Abstract

In this paper, a bi-objective model is presented for dynamic and integrated network design of a new entrant competitive closed-loop supply chain. To consider dynamism and integration in the network design problem, multiple long-term periods are regarded during planning horizon, so that each long-term period includes several short-term periods. Furthermore, a chain to chain competition between two rival supply chains is considered in both forward and reverse logistics. In the forward logistics, the rivals have to compete on the selling price, while in the reverse logistics, the supply chains compete on incentive buying price to achieve more market share. To solve the competitive stage of the proposed model, a game theoretic approach, which determines the selling and incentive buying prices of forward and reverse logistics, is used. Based on the competitive stage's outputs, the resulted dynamic and integrated network design stage is solved using a Pareto-based multi-objective imperialist competitive algorithm. Finally, to evaluate efficiency of the proposed model and solution approach, a numerical study is implemented.

Keywords: Supply chain network design, chain to chain competition, forward/reverse logistics game theoretic approach, Pareto-based meta-heuristic algorithm.

1- Introduction

Nowadays, one of the most important strategic decisions of supply chain management (SCM), which has a significant influence on the future performance of supply chains, is the supply chain network design (SCND) problem. The SCND problem aims to find an efficient structure for a supply chain, so that the flow of good and data among different echelons of supply chain can be facilitated (Simchi-Levi, Kaminsky and Simchi-Levi, 1999). In the literature of SCND problem, many researchers concentrated only on strategic network design decisions, regardless of tactical and operational performance of supply chains. In contrast, reciprocal interaction among infrastructure of a supply chain and future tactical and operational performance of supply chain made some researchers consider short-term decisions integrality, beside strategic supply chain network design problem (Melo, Nickel and Saldanha-da-Gama, 2009; Ghavamifar, Sabouhi and Makui, 2018).

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In this manner, a comprehensive survey about the SCND problem has been studied by Shen (2007). According to the expensive nature of strategic decisions, most researchers studied the SCND problem as an unchangeable single-period problem (Fattahi et al., 2015). On the other hand, some researchers investigated the dynamic SCND problem in which the structure-related decisions can be changed during multiple strategic periods (Mota et al., 2014; Govindan, Jafarian and Nourbakhsh, 2015; Keyvanshokooh et al., 2013; Dubey, Gunasekaran and Childe, 2015; Rahmani, and Mahoodian, 2015). There are a few researches in which several strategic periods and several tactical periods are considered, simultaneously (Badri, Bashiri and Hejazi, 2013).

In the recent years, reducing operational cost, waste management, environmental legislations, government pressures, and etc. made supply chains to consider designing reverse logistics in their networks as well as forward logistic (Kamali et al., 2014; Shi, Zhang and Sha, 2011a; Shi, Zhang and Sha, 2011b; Pishvaee and Razmi, 2012; Soleimani et al., 2017; Kaya and Urek, 2015; Accorsi et al., 2015; Nobari, Kheirkhah and Esmaeili, 2016). In reverse logistics, companies focus on returning products from customer zones and preparing them for reusing. Govindan, Soleimani and Kannan (2015) presented a comprehensive study about reverse logistics and closed-loop supply chains. In this paper, a closed-loop supply chain network design (CLSCND) problem is studied.

In spite of the growing competitive environment in which different supply chains with similar business act in the same markets, most researches evaluate the SCND problem in an uncompetitive and monopoly environment (Fallah, Eskandari and Pishvaee, 2015). Todays, different supply chains can be found in each market and these supply chains have to compete with each other to achieve their goals (Dubey, Gunasekaran and Childe, 2015). Through the studies by which the competition in SCND problem is considered, most of researchers studied the competition within a supply chain and among its different firms, while globalization of services change the inner competition of supply chains into chain to chain form (Zanjirani Farahani et al., 2014; Yazdi and Honarvar, 2015; Makui and Ghavamifar, 2016; Bilir, Onsel Ekici and Ulengin, 2017; Fahimi, Seyedhosseini, and Makui, 2017a; Hosseini-Motlagh, Nematollahi and Nouri, 2018). In a chain to chain competition, different firms of a supply chain cooperate with each other to reach a competitive advantage with respect to the other supply chains. There are a few researches which have studied the competitive SCND problem (Nagurney, Dong and Zhang, 2002; Rezapour, S., and Zanjirani Farahani, 2010; Rezapour et al., 2011; Rezapour, Zanjirani Farahani and Drezner, 2011; Hafezalkotob et al., 2014; Nobari, Kheirkhah and Esmaeili, 2018). A comprehensive study about competitive SCND problem has been provided by Zanjirani Farahani et al., (2014). Most researches in the literature of competitive SCND problem, have focused on competition in forward logistics (Hafezalkotob et al., 2014; Yousefi Yegane, Nakhai Kamalabadi and Farughi, 2016; Saghaeeian and Ramezanian, 2018). A few researches considered the competitive aspects in both forward and reverse logistics (Fallah et al., 2015). In a competitive CLSCND problem, competition in both forward and reverse logistics is regarded.

It is obvious that considering different aspects of the SCND design problem can lead to more realistic and realible results. Accordingly, in this paper, a novel competitive dynamic and integrated supply chain network design problem is presented. In this manner, a multi-objective model is proposed for network design of a new entrant closed-loop supply chain which has to compete with a rival, in both forward and reverse logistics. The main contributions of this paper are as follow:
- Dynamic network design of competitive supply chain, so that the structure of the new entrant supply chain can be changed during several strategic periods.
- Consideration of chain to chain competition in both forward and reverse logistics of supply chain.
- Integration of short-term decisions with strategic long-term network design decisions.
- Presenting an efficient Pareto-based multi-objective meta-heuristic approach, empowered by game theory, to solve the proposed model.

The rest of this paper is organized as follows: Section 2 includes definition of the proposed competitive CLSCND problem for which a multi-objective model is formulated. The solution approach is described in

section 3. Some numerical examples are analysed for the proposed model and the solution approach in section 4. Finally, the conclusion and future research suggestions are given.

2- Problem definition

In this paper, integrated and dynamic network design of a new entrant supply chain, which acts in a competitive environment, is considered. The forward logistics of this supply chain includes several suppliers, manufacturers, and distribution centers (DC) and in the reverse logistics there are several collection centers (CC) and material customers. The manufacturers produce different products using raw materials which are provided by the suppliers and then, send the final products to the DCs. Finally, the distribution centers sell the products in multiple customer zones. In the reverse logistics, the CCs collect the used products from customer zones and sell them to raw material customers. The configuration of this closed-loop supply chain is shown in figure 1.
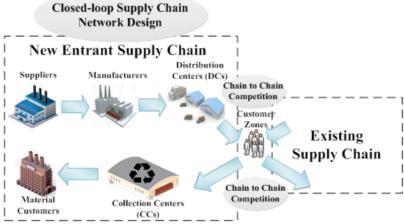

Fig 1. Configuration of the proposed closed-loop supply chain

It is assumed that there is an existing supply chain with a predefined structure which produces the substitutable products and sells them in the customer zones. Hence, the entrant supply chain has to compete with this existing supply chain in two ways:

- In the forward logistics, both supply chains compete with each other to achieve more market share in each customer zone.
- In the reverse logistics, each supply chain aims to collect more used products with respect to the other supply chain.

The competition among these supply chains will be explained more in section 2.3.

It is also supposed that the planning horizon consists of multiple strategic periods so that each strategic period includes several tactical periods. This assumption is considered to integrate tactical decisions with strategic ones. Moreover, it is assumed that the supply chain can extend the capacities of manufacturers during the planning horizon. For each strategic period, there is a defined budget which can be assigned to open new facilities and extend the capacities of current facilities, dynamically.

The aim of the proposed competitive SCND problem is finding the best structure and capacity options for the new entrant closed-loop supply chain with respect to existing supply chain, so that both economic and environmental concerns can be achieved, simultaneously. In each strategic period, the long-term decisions including opening new facilities and extending the capacities of manufacturers are determined, while the short-term decisions would are defined in each tactical period.

The other assumptions of the proposed model are as follow:

- The potential locations for facilities are determined.
- The opened facilities in each strategic period cannot be closed during the next strategic periods.
- The potential capacity options for each manufacturer are determined.

- The maximum capacity of each facility is known.
- The demand function of each customer zone depends linearly only on the selling prices of rivals.
- The accusation function of the used products depends linearly only on the incentive buying prices of both competitive supply chains.
- Shortages can occur in form of the lost sales.
- The budget assigned to each strategic period is determined
- All the parameters are deterministic.

2-1- Notations

All the notations, parameters, and decision variables used in the proposed mathematical mode are stated in table 1.

Table 1. Notations of proposed model

Sets			
R	Set of rivals supply chains ($r, r' \in R$)	S	Set of suppliers ($s \in S$)
M	Set of potential manufacturers ($m \in M$)	D	Set of potential distribution centers ($d \in D$)
K	Set of potential customer zones ($k \in K$)	C	Set of potential collection centers ($c \in C$)
C'	Set of material customers ($c' \in C'$)	P	Set of products ($p \in P$)
P'	Set of raw materials ($p' \in P$)	L	Set of selling price levels ($l \in L$)
L'	Set of return price levels ($l' \in L'$)	N	Set of strategic periods ($n \in N$)
T	Set of tactical periods ($t \in T$)		
Parameters			
FO_i^n	Fixed cost charged in strategic period $n-1$ for opening facility i in strategic period n	FOC_i	Fixed operating cost of facility i
$FA_{m,o}^n$	Fixed cost of manufacturer m charged in strategic period $n-1$ for adding production capacity option o in strategic period n	$FCC_{m,o}^n$	Fixed cost of manufacturer m to operate under capacity option o in strategic period n
$BC_{s,p'}$	Variable cost of buying one unit of product p' from supplier s	$PC_{m,p}$	Variable cost of producing one unit of product p at manufacturer m
$HC_{d,p}$	Variable cost of holding one unit of product p at distribution center d	$SC_{k,p}$	Variable shortage cost of one unit of product p at customer zone k
$TC_{s,m,p'}$	Variable cost of transporting one unit of raw material p' between supplier s and manufacturer m	$TC_{i,j,p}$	Variable cost of transporting one unit of product p between facilities i and j
$SV_{c',p}$	Variable revenue of selling one unit of unrecovered product p to material customer C'	EF_i	Fixed coefficient emission to establish facility i
$EP_{m,p}$	Production emission coefficient to produce one unit of product p at manufacturer m	$ES_{d,p}$	Storage emission coefficient to store one unit of product p at distribution center d
$EC_{c,p}$	Collection emission coefficient to collect one unit of product p at collection center c	$ET_{s,m,p'}$	Transportation emission coefficient to transport one unit of raw material l' from supplier s to manufacturer m
$ET_{i,j,p}$	Transportation emission to transport one unit of product p from facility i to j	Cap_m^{max}	Maximum installable production capacity of manufacturer m
Cap_d^{max}	Maximum storage capacity of distribution center d	Cap_c^{max}	Maximum collecting capacity of collection center c
$Exp_{m,o}$	Capacity expansion of capacity option o at manufacturer m	$\rho_{p'p}$	Quantity of required raw material p' to produce one unit of product p
U_m	Maximum utilization rate of manufacturer m	$Ur_{m,p}$	Usage rate of production capacity for manufacturer m to produce one unit of product p
Ur_i	Usage rate of capacity for facility i	$A_{m,d}$	Number of deliveries from manufacturer m to distribution center d
$\alpha_{k,p}$	Self-selling price elasticity coefficient in demand function of customer zone k for product p	$\alpha'_{k,p}$	Cross-selling price elasticity coefficient in demand function of customer zone k for product p
$\beta_{k,p}$	Self-buying price elasticity coefficient in acquisition function of customer zone k for product p	$\beta'_{k,p}$	Cross-buying price elasticity coefficient in acquisition function of customer zone k for product p
$\theta_{k,p}$	Maximum rate of reusable products for product p in customer zone k	$Demand_{k,p}^{n,t}$	Potential Demand of customer zone k, related to supply chain, for product p in tactical period t of strategic period n

Table 1. Continued

Parameters			
$Dem_{k,p}^{n,t}$	Market share of supply chain in customer zone k for product p in tactical period t of strategic period n	$Ret_{k,p}^{n,t}$	The amount of returned product p from customer zone k in tactical period t of strategic period n
$C_{k,p}^{n,t}$	Mean value of all costs spent by supply chian to provide one unit of product p for customer zone k in each period, considering production, storage and transportation activities	B_n	Budget assigned to strategic period n
$Cost_{total}$	Total cost of supply chain through planning horizon	$Income_{total}$	Total income of supply chain through planning horizon

Decision variables			
Binary variables			
OM_m^n	1 if manufacturer m is open during strategic period n	OD_d^n	if distribution center d is open during strategic period n
OC_c^n	1 if collection center c is open during strategic period n	$O_{m,o}^n$	1 if capacity option o is installed at manufacturer m in strategic period n
Continuous variables			
$Q_{m,p}^{n,t}$	Quantity of product p produced by manufacturer m in tactical period t of strategic period n	$H_{d,p}^{n,t}$	Amount of product p held by distribution center d in tactical period t of strategic period n
$f_{s,m,p'}^{n,t}$	Amount of raw material p' shipped from supplier s to manufacturer m in tactical period t of strategic period n	$f_{i,j,p}^{n,t}$	Amount of product p shipped from facility i to facility j in tactical period t of strategic period n
$S_{k,p}^{n,t}$	Shortage of product p in customer zone k in tactical period t of strategic period n	UC_m^n	Usable capacity of manufacturer m in strategic period n regarding current and preivious strategic periods
$PR_{k,p}^{n,t}$	Selling price of product p to customer zone k in tactical period t of strategic period n	$IPR_{k,p}^{n,t}$	Incentive buying price of product p from customer zone k in tactical period t of strategic period n

2-2- Model formulation

In this sub-section, the objective functions of the multi-objective model are described, and then the constraints are discussed.

2-2-1- Objective functions (OF)

Maximizing total profit of supply chain (equation 1), which is the difference between total income (equation 1a) and total cost (equation 1b) of supply chain, is the first objective function of proposed model.

$$Max\ OF_1 = Income_{total} - Cost_{total} \tag{1}$$

$$Income_{total} = \sum_{n \in N, n>0} \sum_{t \in T} \sum_{d \in D} \sum_{k \in K} \sum_{p \in P} PR_{k,p}^{n,t} f_{d,k,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{c \in C} \sum_{c' \in C'} \sum_{p \in P} SV_{c',c,p} f_{c',c,p}^{n,t} \tag{1a}$$

$$Cost_{Var} = \sum_{n \in N, n>0} \sum_{m \in M} FOC_m^n OM_m^n + \sum_{n \in N, n>0} \sum_{d \in D} FOC_d^n OD_d^n + \sum_{n \in N, n>0} \sum_{c \in C} FOC_c^n OC_c^n + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{o \in O} \sum_{0 < n' \le n} FCC_{m,o}^n O_{m,o}^{n'}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} BC_{s,p'} f_{s,m,p'}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{m \in M} \sum_{p \in P} PC_{m,p} Q_{m,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{d \in D} \sum_{p \in P} HC_{m,p} \left(H_{d,p}^{n,t} + \frac{1}{2} \sum_{m \in M} \frac{f_{m,d,p}^{n,t}}{A_{m,d}} \right)$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{k \in K} \sum_{p \in P} \sum_{l \in L} SC_{k,p} S_{k,p,l}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{k \in K} \sum_{c \in C} \sum_{p \in P} IPR_{k,p}^{n,t} f_{k,c,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} TC_{s,m,p'} f_{s,m,p'}^{n,t} \tag{1b}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{m \in M} \sum_{d \in D} \sum_{p \in P} TC_{m,d,p} f_{m,d,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{d \in D} \sum_{k \in K} \sum_{p \in P} TC_{d,k,p} f_{d,k,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} TC_{k,c,p} f_{k,c,p}^{n,t}$$

Recently, green manufacturing has been attended widely in the SCND problem (Ma et al., 2018; Hosseini-Motlagh, Laari, Toyli and Ojala, 2017; Nematollahi and Nouri, 2018). In this manner, life cycle analysis (LCA) method, by which the released waste is quantified through the product life cycle, helps firms to consider environmental performance (Liu, Qiu and Chen, 2014; Rabbani, Keshvarparast and Farrokhi-Asl, 2016). Hence, minimizing the amount of emissions arising from establishment, operation and transportation of the facilities is regarded as the second objective function of the proposed model which is stated by equation 2.

$$Min\ OF_2 = \sum_{m \in M} EF_m OM_m^{NT} + \sum_{d \in D} EF_d OM_d^{NT} + \sum_{c \in C} EF_c OC_c^{NT}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{m \in M} \sum_{p \in P} EP_{m,p} Q_{m,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{d \in D} \sum_{p \in P} ES_{d,p} H_{d,p}^{n,t}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{k \in K} \sum_{c \in C} \sum_{p \in P} EC_{c,p} f_{k,c,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} ET_{s,m,p'} f_{s,m,p'}^{n,t}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{m \in M} \sum_{d \in D} \sum_{p \in P} ET_{m,d,p} f_{m,d,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{d \in D} \sum_{k \in K} \sum_{p \in P} ET_{d,k,p} f_{d,k,p}^{n,t}$$

$$+ \sum_{n \in N, n>0} \sum_{t \in T} \sum_{k \in K} \sum_{c \in C} \sum_{p \in P} ET_{k,c,p} f_{k,c,p}^{n,t} + \sum_{n \in N, n>0} \sum_{t \in T} \sum_{c \in C} \sum_{c' \in C'} \sum_{p \in P} ET_{c,c',p} f_{c,c',p}^{n,t}$$

(2)

2-2-2- Constraints

$$\sum_{s \in S} f_{s,m,p'}^{n,t} = \sum_{p \in P} \rho_{p',p} Q_{m,p}^{n,t} \quad \forall m, p', n > 0, t \tag{3}$$

$$Q_{m,p}^{n,t} = \sum_{d \in D} f_{m,d,p}^{n,t} \quad \forall m, p, n > 0, t \tag{4}$$

$$H_{d,p}^{n,t-1} + \sum_{m \in M} f_{m,d,p}^{n,t} = H_{d,p}^{n,t} + \sum_{k \in K} f_{d,k,p}^{n,t} \quad \forall d, p, n, t \neq 1 \tag{5}$$

$$H_{d,p}^{n-1,T} + \sum_{m \in N} f_{m,d,p}^{n,t} = H_{d,p}^{n,t} + \sum_{k \in K} f_{d,k,p}^{n,t} \quad \forall d, p, n, t = 1 \tag{6}$$

$$\sum_{k \in K} f_{k,c,p}^{n,t} = \sum_{c' \in C'} f_{c,c',p}^{n,t} \quad \forall c, p, n > 0, t \tag{7}$$

$$\sum_{d \in D} f_{d,k}^{n,t} + S_{k,p}^{n,t} = Dem_{k,p}^{n,t} \quad \forall p, n > 0, t \tag{8}$$

$$\sum_{c \in C} f_{k,c,p}^{n,t} \leq \sum_{d \in D} f_{d,k,p}^{n,t} \tag{9}$$

$$OM_m^n \geq OM_m^{n-1} \quad \forall m, n > 0 \tag{10}$$

$$OD_d^n \geq OD_d^{n-1} \quad \forall d, n > 0 \tag{11}$$

$$OC_c^n \geq OC_c^{n-1} \quad \forall c, n > 0 \tag{12}$$

$$\sum_{m \in M} FO_m^{n+1} \left(OM_m^{n+1} - OM_m^n \right) + \sum_{d \in D} FO_d^{n+1} \left(OD_m^{n+1} - OD_m^n \right)$$

$$+ \sum_{c \in C} FO_c^{n+1} \left(OC_m^{n+1} - OC_m^n \right) + \sum_{m \in M} \sum_{o \in O} FA_{m,o}^{n+1} \left(O_{m,o}^{n+1} \right) \leq B^n \tag{13}$$

$$\sum_{o \in O} O_{m,o}^n \leq OM_m^n \quad \forall m, n > 0 \tag{14}$$

$$UC_m^n = \sum_{n' \leq n, n' \in N} \sum_{o \in O} Exp_{m,o} O_{m,o}^{n'} \quad \forall m, n > 0 \tag{15}$$

$$\sum_{p \in P} Ur_{m,p} Q_{m,p}^{n,t} \leq U_m UC_m^n \quad \forall m, n > 0, t \tag{16}$$

$$UC_m^n \leq Cap_m^{max} OM_m^n \quad \forall m, n > 0 \tag{17}$$

$$\sum_p Ur_p H_{d,p}^{n,t} + \frac{1}{2} \sum_{m \in M} \sum_{p \in P} Ur_p \frac{f_{m,d,p}^{n,t}}{A_{m,d}} \leq OD_d^n Cap_d^{max} \quad \forall d, n > 0, t \tag{18}$$

$$\sum_{k \in K} \sum_{p \in P} f_{k,c,p}^{n,t} \leq OC_c^n Cap_c^{\max} \quad \forall c, n > 0, t \tag{19}$$

$$OM_m^n, OD_d^n, OC_c^n, O_{m,o}^n = \{0,1\}$$

$$Q_{m,p}^{n,t}, H_{d,p}^{n,t}, f_{s,m,p'}^{n,t}, f_{i,j,p}^{n,t}, S_{k,p,l}^{n,t}, PR_{k,p}^{n,t}, IPR_{k,p}^{n,t}, UB_n \geq 0 \tag{20}$$

Equation 3 confirms that each manufacturer buys sufficient raw material from suppliers. Equation 4 indicates all the products are transported to the distribution centers in each period. Equation 5 and equation 6 assure that in each tactical period, the sum of input products and stored products of the previous tactical period equals to the output products plus the amount of products stored in current tactical period. Equation 7 indicates each collection center sells all the products collected from the customer zones. Equation 8 states that in each period, the sum of delivered products to customer zones and shortage equals to the corresponding market share in that period. Equation 9 indicates the amount of returned products in each period which is less than provided market share. Equations 10 and 12 confirms that open facilities cannot be closed in next periods. Equation 13 limits the fixed cost of opening facilities to the assigned budget of strategic periods. Equation 14 assures that only one capacity option can be activated in each strategic period. Equation 15 calculates the usable capacities for each manufacturer based on current and previous strategic periods. Equation 16 confirms that in each tactical period, the employed capacity in each manufacturer is less than the maximum utilization rate. Equation 17 limits the overall capacity manufacturers. Equation 18 and equation 19 express the capacity limitation of DCs and CCs, respectively. Finally, equation 20 indicates the decision variables.

2-3- Competition of supply chain
In this sub-section, the competitions among the new entrant and existing supply chains in forward and reverse logistics are formulated.

The demand in competitive markets depends on performance of all competitors. In this paper, the linear price-sensitive demand function, which is a known price-sensitive demand function, is considered to formulate the demand function of each customer zone for supply chains (Fattahi et al., 2015). Equation 21 indicates the market share of supply chain r with respect to both rival supply chains

$$Dem_{r,k,p}^{n,t} = Demand_{r,k,p}^{n,t} - \alpha_{r,k,p} PR_{r,k,p}^{n,t} + \alpha'_{r',k,p} PR_{r',k,p}^{n,t} \tag{21}$$

Where $PR_{r,k,p}^{n,t}$ and $PR_{r',k,p}^{n,t}$ indicates the selling price of supply chain r and its rival (r'), respectively.

Furthermore, it is also assumed that there is a competition among supply chains in returning reusable products. In the recent years, competition in reverse logistics is regarded in some researches (Wu and Zhou, 2017). Hence, a simple linear price-sensitive acquisition function is considered to formulate the relationship among the amount of returned products and buying prices of supply chains which can be formulated as equation 22.

$$\text{Re}\,t_{r,k,p}^{n,t} = \theta_{r,k,p} Demand_{r,k,p}^{n,t} - \beta_{r,k,p} IPR_{r,k,p}^{n,t} + \beta'_{r',k,p} IPR_{r',k,p}^{n,t} \tag{22}$$

Where $IPR_{r,k,p}^{n,t}$ and $IPR_{r',k,p}^{n,t}$ are incentive buying price of supply chain r and its rival (r'), respectively. Indeed, equation 22 indicates the market share of entrant supply chain in returning used products.

Based on selling products in forward logistics and selling returned products in reverse logistics, the profit function of supply chain r, in each customer zone and in each tactical period can be formulated as equation 23.

$$\Pi_{r,k,p}^{n,t} = \left(PR_{r,k,p}^{n,t} - C_{r,k,p}^{n,t}\right)\left(Dem_{r,k,p}^{n,t}\right) + \left(SV_{c',p}^{n,t} - IPR_{r,k,p}^{n,t}\right)\left(\text{Re}\,t_{r,k,p}^{n,t}\right) \tag{23}$$

In order to solve the model, the competitive part of the proposed model is solved first. Then, the defined selling and buying prices are substituted in the formulated model. The solution approach is more explained in section 4.

3- Solution approach

In this paper, the solution approach contains two steps. First, the game theory approach is used to solve the competitive pricing problem, as discussed in subsection 3-1. The outputs of this step (selling and incentive buying prices) are substituted in the proposed model, and then a meta-heuristic algorithm is used to solve the achieved model, as presented in subsection 3-2. Figure 2 indicates two steps of the solution approach.
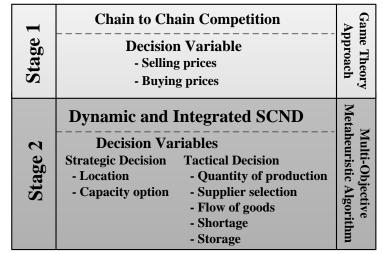
Stage 1	**Chain to Chain Competition**	**Game Theory Approach**
	Decision Variable - Selling prices - Buying prices	
Stage 2	**Dynamic and Integrated SCND**	**Multi-Objective Metaheuristic Algorithm**

	Decision Variables
	Strategic Decision **Tactical Decision**
	- Location - Quantity of production
	- Capacity option - Supplier selection
	                           - Flow of goods
	                           - Shortage
	                           - Storage	

Fig 2. Steps of solution approach

3-1- Competitive step

As mentioned in section 2-3, simultaneous competitions in both forward and reverse logistics exist among the new entrant and existing supply chains. In fact, in each customer zone, both supply chains have to determine their selling and incentive buying prices with respect to the competitor supply chain. To solve these competitions, the game theory approach, by which the equilibrium values for selling prices and incentive buying prices are obtained, is used. Since in this type of competitions, players define their decisions simultaneously, Nash equilibrium can be achieved for the supply chains based on Fallah et al. (2015).

To find the optimum value of selling and incentive buying prices, the concavity of profit function of equation 23 is evaluated with respect to these competitive decision variables. So, the first and second order derivations of the profit function to selling and buying prices are calculated using equations 24 to 29.

$$\frac{\partial \Pi_{r,k,p}^{n,t}}{\partial PR_{r,k,p}^{n,t}} = Demand_{r,k,p}^{n,t} - 2\alpha_{r,k,p}PR_{r,k,p}^{n,t} + \alpha'_{r',k,p}PR_{r',k,p}^{n,t} + \alpha_{r,k,p}C_{r,k,p}^{n,t} \tag{24}$$

$$\frac{\partial \Pi_{r,k,p}^{n,t}}{\partial IPR_{r,k,p}^{n,t}} = \beta'_{r',k,p}IPR_{r',k,p}^{n,t} - 2\beta_{r,k,p}IPR_{r,k,p}^{n,t} - \theta_{r,k,p}Demand_{r,k,p}^{n,t} + \beta_{r,k,p}SV_{c',p}^{n,t} \tag{25}$$

$$\frac{\partial^2 \Pi_{r,k,p}^{n,t}}{\partial PR_{r,k,p}^{n,t}{}^2} = -2\alpha_{r,k,p} \tag{26}$$

$$\frac{\partial^2 \Pi_{r,k,p}^{n,t}}{\partial PR_{r,k,p}^{n,t}\partial IPR_{r,k,p}^{n,t}} = 0 \tag{27}$$

$$\frac{\partial^2 \Pi_{r,k,p}^{n,t}}{\partial IPR_{r,k,p}^{n,t}{}^2} = -2\beta_{r,k,p} \tag{28}$$

$$\frac{\partial^2 \Pi_{r,k,p}^{n,t}}{\partial IPR_{r,k,p}^{n,t} \partial PR_{r,k,p}^{n,t}} = 0 \tag{29}$$

The Hessian matrix can be calculated using equation 30.

$$H = \begin{bmatrix} -2\alpha_{r,k,p} & 0 \\ 0 & -2\beta_{r,k,p} \end{bmatrix} \tag{31}$$

Based on equation 27, the Hessian matrix is definitely negative ($\det(H) > 0$). Hence, the profit function is concave.

Accordingly, the optimal values of selling and incentive buying prices can be calculated by setting the first order partial derivations to zero, as formulated by equations 31 and 32.

$$\frac{\partial \Pi_{r,k,p}^{n,t}}{\partial PR_{r,k,p}^{n,t}} = Demand_{r,k,p}^{n,t} - 2\alpha_{r,k,p}PR_{r,k,p}^{n,t} + \alpha'_{r',k,p}PR_{r',k,p}^{n,t} + \alpha_{r,k,p}C_{r,k,p}^{n,t} = 0 \tag{31}$$

$$\frac{\partial \Pi_{r,k,p}^{n,t}}{\partial IPR_{r,k,p}^{n,t}} = \beta'_{r',k,p}IPR_{r',k,p}^{n,t} - 2\beta_{r,k,p}IPR_{r,k,p}^{n,t} - \theta_{r,k,p}Demand_{r,k,p}^{n,t} + \beta_{r,k,p}SV_{c',p}^{n,t} = 0 \tag{32}$$

By solving these equations, the optimal values for selling and incentive buying prices are calculated using equations 33 and 34.

$$PR_{r,k,p}^{n,t}* = \frac{\alpha'_{r',k,p}Demand_{r,k,p}^{n,t} + 2\alpha'_{r',k,p}\left(Demand_{r,k,p}^{n,t} + \alpha_{r,k,p}C_{r,k,p}^{n,t}\right) + \alpha_{r',k,p}\alpha'_{r',k,p}C_{r',k,p}^{n,t}}{4\alpha_{r,k,p}\alpha_{r',k,p} - \alpha'_{r,k,p}\alpha'_{r',k,p}} \tag{33}$$

$$IPR_{r,k,p}^{n,t}* = \frac{\beta_{r',k,p}\beta'_{r',k,p}SV_{c',p}^{n,t} + 2\beta_{r,k,p}\beta_{r',k,p}SV_{c',p}^{n,t} - 2\beta_{r,k,p}\theta_{r,k,p}Demand_{r,k,p}^{n,t} - \beta'_{r',k,p}\theta_{r',k,p}Demand_{r,k,p}^{n,t}}{4\beta_{r,k,p}\beta_{r',k,p} - \beta'_{r,k,p}\beta'_{r',k,p}} \tag{34}$$

Now, the optimal values for selling and incentive buying prices which are calculated regarding the chain to chain competition should be substituted in the proposed model stated in equations 1 to 20.

3-2- Dynamic and integrated network design step

According to the optimal values, resulted in the competitive stage, a MINLP bi-objective model is achieved. Recently, the confliction among different goals of multi-objective problems, made many researchers use Pareto-based meta-heuristic algorithm to solve multi-objective models. In these types of models, there are several objective functions including $OF(\vec{x}) = [OF_1(\vec{x}),...,OF_m(\vec{x})]$ with respect to multiple constraints such as $g_i(\vec{x}) \leq 0$, $i = 1, 2, ..., c$, $\vec{x} \in X$, where $\vec{x}$ is the solution vector and X is the feasible region. In a maximization form, the domination of solution $\vec{a}$ to solution $\vec{b}$ $(\vec{a}, \vec{b} \in X)$ can be described as follows:

1) $f_i(\vec{a}) \geq f_i(\vec{b}), \quad \forall i = 1, 2, ..., m$

2) $\exists i \in \{1, 2, ..., m\}: f_i(\vec{a}) > f_i(\vec{b})$

Pareto solutions (Pareto fronts) consist of solutions which cannot dominate each other. The goodness of these solutions can be evaluated by diversity and convergence of the solutions (Deb et al., 2002).

In this paper, in order to solve the proposed multi-objective model, a multi-objective imperialist competitive algorithm (MOICA) which is a Pareto-based meta-heuristic algorithm is used.

3-2-1- Multi-objective imperialist competitive algorithm

Imperialist competitive algorithm (ICA) is a meta-heuristic algorithm which is inspired by a social phenomenon, called imperialism. For the first time, Atashpaz-Gargari and Lucas (2007) introduced this algorithm. The capabilities of ICA in solving single-objective models encouraged many researchers to use

multi-objective version of ICA. MOICA which is a Pareto-based meta-heuristic algorithm is introduced by Enayatifar et al. (2013).

In this paper, MOICA is used to solve the multi-objective model. The steps of proposed MOICA are as follows:

- *Step 1*: *Initializing the empires*

In this step N_{pop} countries (number of population) are created, randomly. The solution representation for the proposed model includes two parts, as shown in Figure 3:

- Part 1: A vector with $M+D+C$ cells (number of manufacturers, DCs, CCs). The value of each cell includes a number between 0 to N, which indicates the strategic periods in which the related facility is opened. Zero value indicates that the facility stays closed during the planning horizon.
- Part 2: A $M \times N$ matrix which determines the activated capacity option for manufacturers in each strategic period.

In order to create the countries, the values of these vectors should be initialized for each country, and then based on these defined values, the other tactical decision variables for each solution are created, randomly.

Fig 3. Solution representation

Now, N_{imp} of most powerful created countries are selected as imperialists for whom the other remaining countries are colonies. Number of colonies, assigned to each imperialist, is based on two following criteria which indicate the power of imperialist:

1- Rank of each country, which is based on the fast non-dominated sorting (FNDS) technique and considers all the objective functions.
2- Merit of each country, compared to countries with the same rank, which is based on the crowding distance criterion.

Based on Enayatifar et al. (2013), the power of each country is calculated using equation 35.

$$Power_n = \left(\sum_{j=1}^{D} \left[OF_j(n) \middle/ \sum_{i=1}^{N_{rank}(C)} OF_j(i) \right] (Rank(C)-1) \times D \right)^{-1} \tag{35}$$

Where D is the number of objective functions $OF_j(i)$ is value of the jth objective function of country i and $N_{rank}(C)$ is the number of countries in rank C.

Now, the number of countries, assigned to each imperialist (NC), is using equation 36:

$$NC_n = round\{p_n N_{col}\} \tag{36}$$

Where $p_n = \dfrac{power_n}{\sum_{i=1}^{N_{imp}} power_i}$, indicates the imperialists power ratio.

- *Step 2: Moving of the colonies toward their imperialist*

In this algorithm, it is assumed that the colonies, seized by imperialist, move gradually toward the position of their imperialist and a deviation might occur during this movement. The movement of each colony and its possible deviation can be calculated using equation 37 and equation 38, respectively.

$$x \sim U(0, \beta \times d) \tag{37}$$

$$\theta \sim U(-\gamma, \gamma) \tag{38}$$

Where $U(.)$ is a random variable with Uniform distribution function, d indicates the distance among colony and its imperialist and β and γ are parameters of the algorithm.

- *Step 3: Exchanging position of imperialist and colony*

It is possible that colonies reach a more powerful position with respect to their imperialist. So, after the movements for each colony, its power is calculated again. If the power of the colony is larger than its imperialist's power, the exchange between this colony and its imperialist is considered so that this powerful colony is known as the new imperialist of the related empire.

- *Step 4: Computing the total cost of all empires*

In this step, the power of each empire which is based on its imperialist's power and a portion of its colonies' power is calculated, as equation 39.

$$TC_n = Cost(imperialist_n) + \zeta\, mean\{cost(colonies)\} \tag{39}$$

Where ζ is a positive number less than 1 that indicates the effect of the colonies' mean cost on the imperialist cost.

- *Step 5: Imperialist competition*

The imperialist competition among different empires is considered in this step. During this competition, the most powerful empire seizes the weakest colony of the weakest empire. To normalize the power of each empire (NTC_n), equation 40 is used.
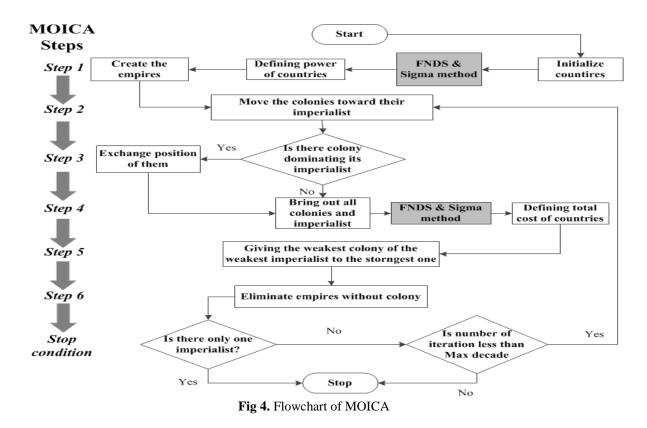
$$NTC_n = TC_n - \max\{TC_n\} \tag{40}$$

- *Step 6: Eliminating the powerless empires*

An empire without any colony is eliminated in this step. Hence, the remained empires continue the competition.

- *Stop condition*

If only one empire remains, the algorithm will stop. It is also assumed that if the number of iterations exceeds a predefined maximum decade, the algorithm will stop.

The flowchart of proposed MOICA is shown in figure 4 (Multi-objective parts are indicated with different colors).

Fig 4. Flowchart of MOICA

4- Numerical study

In this section, the proposed model and solution approach are evaluated using several numerical examples. Also, the sensitivity analysis is implemented. The generated test problems are solved using solution approach in section 4-1. Section 4-2 describes the sensitivity analysis with respect to the competitive coefficients. It is notable that the MATLAB Software (Version 7.10.0.499, R2010a) on a 2 GHz laptop with 8 GB RAM, is used to solve the generated problems. Also, to adjust the parameters of MOICA, Taguchi method is used (Fattahi, Hajipour and Nobari, 2015). In this manner, the L27 design is implemented using Minitab Software for MOICA.

4-1- Numerical examples

Unfortunately, there is no benchmark problem in the literature of competitive supply chain network design problem (Fahimi, Seyedhosseini and Makui, 2017b). Hence, in this paper, 10 test problems are randomly generated to evaluate the proposed model and the solution approach. The main characteristics of test problems are indicated in table 2. The other parameters of the model are randomly generated using Uniform distribution functions in a reasonable range.

Table 2. Characteristics of test problems

Problem No.	S	M	D	K	C	C'	P'	P	N	T
P1	2	2	3	2	2	1	2	2	2	3
P2	3	3	4	4	3	1	2	2	2	3
P3	3	4	5	5	3	2	3	3	3	3
P4	4	6	6	7	4	3	4	4	3	3
P5	4	6	7	8	4	3	5	4	3	3
P6	4	7	7	9	5	3	5	4	3	3
P7	5	7	8	10	5	3	6	4	3	3
P8	6	9	12	13	7	3	9	5	4	3
P9	8	11	13	18	8	4	9	7	4	3
P10	10	15	15	20	10	5	10	10	5	3

To solve the generated test problems, the competitive stage, as stated in section 3-1, is respected first. Based on this stage, selling prices, incentive buying prices, market share of supply chains and the amount of returned products, for each tactical period of the strategic periods is defined. The results of the competitive stage for all test problems are indicated in table 3. It should be noted that the average values of these variables with respect to all customer zones, tactical and strategic periods are reported in table 3.

Table 3. Competitive stage's results

Problem No.	Supply chain	PR	Dem	IPR	Ret	Π	OF1	OF2
P1	New entrant SC	1177.8	1849	46.97	911	1255777	9737687	1526232
	Existing SC	1462.2	1924	64.51	989	2054594		
P2	New entrant SC	1258.1	1908	10.44	1071	1587530	23433371	2811082
	Existing SC	1105.7	1696	29.97	1053	1323721		
P3	New entrant SC	1240.7	1794	28.45	977	1375879	38123554	5441700
	Existing SC	1058.2	1897	63.11	1066	1295817		
P4	New entrant SC	1103.1	1660	62.45	1045	1098345	43783893	6925080
	Existing SC	1215.4	1788	39.83	1068	1549302		
P5	New entrant SC	1013.7	1406	67.99	1044	820155	42904860	12743575
	Existing SC	1104.1	1760	53.05	913	1486366		
P6	New entrant SC	1114.9	1544	37.73	1049	1070500	57489721	22894046
	Existing SC	889.4	1557	57.37	970	841900		
P7	New entrant SC	1425	1670	66	1359	2445469	80564936	45914352
	Existing SC	944	1519	68	1146	1550214		
P8	New entrant SC	1204.6	1692	59.65	1081	1300449	87667503	59345081
	Existing SC	949.7	1663	61.04	1027	952741		
P9	New entrant SC	1156.6	1447	66.86	839	1010727	150926132	71214097
	Existing SC	943.6	1596	51.69	918	938654		
P10	New entrant SC	1385.7	1964	39.29	1173	1867788	265507330	86486845
	Existing SC	1548.5	2201	5.37	1207	2707293		

According to the calculated selling and buying prices and respecting the market share of supply chain in each customer zone, the new dynamic and integrated network design stage for the new entrant CLSC can be solved, as discussed in section 3.2.

Using MOICA to solve the network design stage leads a Pareto-front for each test problem. Two last columns of table 3 indicate the objective functions for each test problem. Since Pareto-front of each test problem includes several solutions, the average values for the objective functions are reported in table 3.

Furthermore, the objective functions of the final Pareto-front for test problem P6 are indicated in table 4. It is observed that using MOICA leads to 8 solutions which cannot dominate each other, so that the decision maker can select the desirable solution among them.

Figure 5 indicates the five last Pareto-fronts which are obtained from solving test problem P6 by MOICA. Accordingly, the improvement of solutions during sequential iterations can be observed in figure 5.

Table 4. Pareto-front of test problem P6

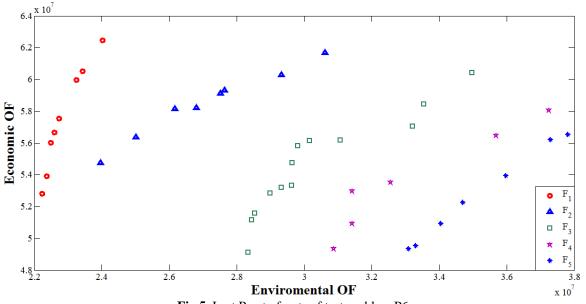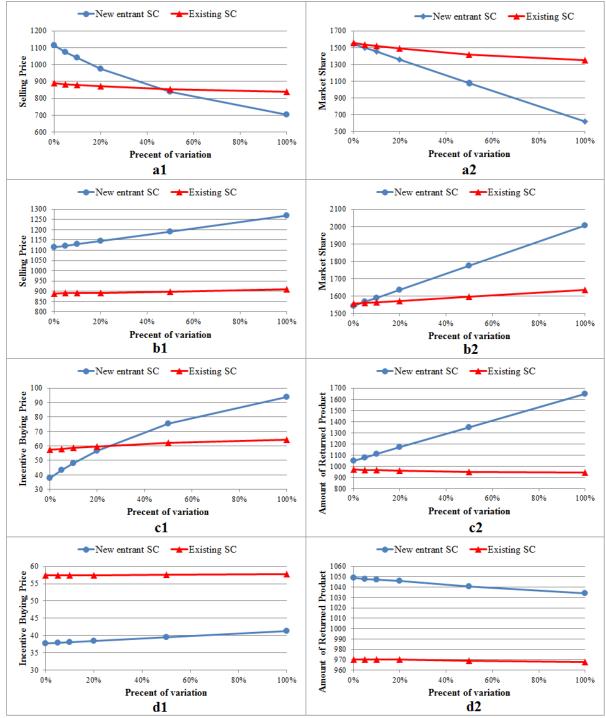| Pareto solution No.	Objective Function 1	Objective Function 2
1	62467509	24032438
2	52819794	22239681
3	60520857	23428987
4	59966710	23253986
5	57551143	22730255
6	56674397	22601808
7	53902955	22371966
8	56014400	22493244

Fig 5. Last Pareto fronts of test problem P6

Fig 6. Sensitivity analysis of selling and buying prices' eclasticity coefficient

4-2- Sensitivity analysis

Based on the interactions exist among the short-term pricing decisions and the strategic network design problem, in this section a sensitivity analysis on elasticity coefficients, is implemented for test problem P6.

Figure 6(a) indicates the impact of self-selling price elasticity coefficients ($\alpha_{r,k,p}$) on the market shares ($Dem_{k,p}^{n,t}$) and selling prices ($PR_{k,p}^{n,t}$).As it is expected, the market share and selling prices decrease when $\alpha_{r,k,p}$ increases. In fact, larger values for self-price elasticity coefficient ($\alpha_{r,k,p}$) result in more sensitivity of market share to selling price of the relevant supply chain. So, the supply chain has to set smaller selling prices to attract more customers.

Figure 6(b) indicates the effect of cross-selling price elasticity coefficients ($\alpha'_{r',k,p}$) on selling price ($PR_{k,p}^{n,t}$) and market share ($Dem_{k,p}^{n,t}$). It is observed that $\alpha'_{r',k,p}$ has a positive influence on the selling prices and market shares which means increasing $\alpha'_{r',k,p}$ encourages supply chain r to set higher selling prices, so that its market share is increased, significantly.

Figure 6(c) indicates the changes of incentive buying price ($IPR_{k,p}^{n,t}$) and the amount of returned product ($Ret_{k,p}^{n,t}$) with respect to the changes of self-buying price elasticity coefficients ($\beta_{r,k,p}$). It is observed that $\beta_{r,k,p}$ has influences on the buying price and the amount of returned products, positively.

Figure 6(d) confirms the negative impact of the cross-buying price elasticity coefficients ($\beta_{r',k,p}$) on the amount of returned products. As a result, the supply chain r has to increase the incentive buying prices to compensate this disability.

Finally, figure 7 indicates the effect of selling price's elasticity coefficients on the economic objective functions for both competitive and network design stages. It is obvious that, increasing this parameter leads to less selling price and market share. Hence, the profit of supply chain is decreased. Since the fixed opening cost is not considered in the competitive stage, there is a difference between two stages' profit. Also, the competitive stage is solved based on selling products in all customer zones, while some customer zones might be missed in the network design stage.
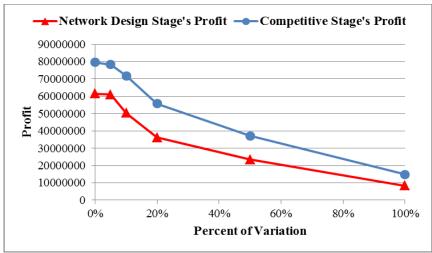

Fig 7. Variations of economic OF vs. selling price's eclasticity coefficient

5- Conclusion

In this paper, a bi-objective model was proposed for the dynamic and integrated closed-loop supply chain network design problem in a competitive environment which attempted to optimize both economic and environmental concerns. The proposed dynamic model included several strategic periods. Furthermore, to integrate short-term tactical and operational decisions with strategic ones, multiple tactical periods were considered in each strategic period. Also, a chain to chain competition on selling prices of forward logistics and buying prices of reverse logistics was regarded. To solve the proposed

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model, the competitive stage is considered first, in which the game theory approach is used to determine the optimal selling and buying prices. Based on these resulted prices in the model, the achieved bi-objective network design stage was solved using the Pareto-based multi-objective imperialist competitive algorithm. Finally, the proposed model and solution approach were evaluated using several numerical examples.

In this paper selling and buying prices are considered as competitive factors, while the other competitive factors such as quality and service level can be regarded in the chain to chain competition. The model can also be extended by consideration of the uncertainty and different scenarios for the parameters. Finally, using bi-level programming approach in solving the proposed model may lead to more accurate and reliable results.

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