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; Pishvae 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 Pishvae, 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, Nakhi Kamalabadi and Faroughi, 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.

![Configuration of the proposed closed-loop supply chain](image)

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 be 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 model are stated in Table 1.

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<td>( M )</td>
<td>Fixed cost of manufacturer ( m ) charged in strategic period ( n-1 ) for adding production capacity option ( o ) in strategic period ( n )</td>
<td>( M )</td>
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<tr>
<td>( K )</td>
<td>Variable cost of buying one unit of product ( p' ) from supplier ( s )</td>
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<tr>
<td>( C' )</td>
<td>Variable cost of holding one unit of product ( p ) at distribution center ( d )</td>
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<td>( P' )</td>
<td>Variable cost of transporting one unit of raw material ( p' ) between supplier ( s ) and manufacturer ( m )</td>
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<td>( L' )</td>
<td>Variable revenue of selling one unit of unrecovered product ( p ) to material customer ( c' )</td>
<td>( L' )</td>
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<td>( T )</td>
<td>Variable revenue of selling one unit of unrecovered product ( p ) to material customer ( c' )</td>
<td>( T )</td>
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</table>

| \( FQ^n \) | Fixed operating cost of facility \( i \) | \( FQ^n \) | Fixed cost charged in strategic period \( n-1 \) for opening facility \( i \) in strategic period \( n \) |
| \( FA_{m,o}^n \) | Fixed cost of manufacturer \( m \) to operate under capacity option \( o \) in strategic period \( n \) | \( FA_{m,o}^n \) | Fixed cost of manufacturer \( m \) charged in strategic period \( n-1 \) for adding production capacity option \( o \) in strategic period \( n \) |
| \( BC_{s,p'} \) | Variable cost of buying one unit of product \( p' \) from supplier \( s \) | \( BC_{s,p'} \) | Variable cost of buying one unit of product \( p' \) from supplier \( s \) |
| \( HC_{d,p} \) | Variable cost of holding one unit of product \( p \) at distribution center \( d \) | \( HC_{d,p} \) | Variable cost of holding one unit of product \( p \) at distribution center \( d \) |
| \( TC_{s,m,p'} \) | Variable cost of transporting one unit of raw material \( p' \) between supplier \( s \) and manufacturer \( m \) | \( TC_{s,m,p'} \) | Variable cost of transporting one unit of raw material \( p' \) between supplier \( s \) and manufacturer \( m \) |
| \( SV_{c',p} \) | Variable revenue of selling one unit of unrecovered product \( p \) to material customer \( c' \) | \( SV_{c',p} \) | Variable revenue of selling one unit of unrecovered product \( p \) to material customer \( c' \) |
| \( EP_{p,p} \) | Production emission coefficient to produce one unit of product \( p \) at manufacturer \( m \) | \( EP_{p,p} \) | Production emission coefficient to produce one unit of product \( p \) at manufacturer \( m \) |
| \( EC_{c,p} \) | Collection emission coefficient to collect one unit of product \( p \) at collection center \( c \) | \( EC_{c,p} \) | Collection emission coefficient to collect one unit of product \( p \) at collection center \( c \) |
| \( ET_{i,j,p} \) | Transportation emission coefficient to transport one unit of product \( p \) from facility \( i \) to \( j \) | \( ET_{i,j,p} \) | Transportation emission coefficient to transport one unit of product \( p \) from facility \( i \) to \( j \) |
| \( C_{d,\text{max}} \) | Maximum storage capacity of distribution center \( d \) | \( C_{d,\text{max}} \) | Maximum storage capacity of distribution center \( d \) |
| \( Exp_{m,o} \) | Capacity expansion of capacity option \( o \) at manufacturer \( m \) | \( Exp_{m,o} \) | Capacity expansion of capacity option \( o \) at manufacturer \( m \) |
| \( U_m \) | Maximum utilization rate of manufacturer \( m \) | \( U_m \) | Maximum utilization rate of manufacturer \( m \) |
| \( U_{i,t} \) | Usage rate of capacity for facility \( i \) | \( U_{i,t} \) | Usage rate of capacity for facility \( i \) |
| \( \alpha_{k,p} \) | Self-selling price elasticity coefficient in demand function of customer zone \( k \) for product \( p \) | \( \alpha_{k,p} \) | Self-selling price elasticity coefficient in demand function of customer zone \( k \) for product \( p \) |
| \( \beta_{k,p} \) | Cross-selling price elasticity coefficient in demand function of customer zone \( k \) for product \( p \) | \( \beta_{k,p} \) | Cross-selling price elasticity coefficient in demand function of customer zone \( k \) for product \( p \) |
| \( \theta_{k,p} \) | Maximum rate of reusable products for product \( p \) in customer zone \( k \) | \( \theta_{k,p} \) | Maximum rate of reusable products for product \( p \) in customer zone \( k \) |
| \( Demand_{k,p} \) | Potential Demand of customer zone \( k \), related to supply chain, for product \( p \) in tactical period \( t \) of strategic period \( n \) | \( Demand_{k,p} \) | Potential Demand of customer zone \( k \), related to supply chain, for product \( p \) 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.

\[
\text{Max } OF_1 = \text{Income}_{\text{total}} - \text{Cost}_{\text{total}}
\]

\[
\text{Income}_{\text{total}} = \sum_{n_1, n_2, n_3, n_4} \sum_{t=1}^{T} \sum_{d=1}^{D} \sum_{k=1}^{K} \sum_{p=1}^{P} \text{PR}_{n_1, n_2, n_3, n_4}^{t, d, k, p} \cdot f_{n_1, n_2, n_3, n_4}^{t, d, k, p} + \sum_{n_1, n_2, n_3, n_4} \sum_{t=1}^{T} \sum_{c=1}^{C} \sum_{c'=1}^{C'} \sum_{p=1}^{P} \text{SV}_{n_1, n_2, n_3, n_4}^{t, c, c', p} \cdot f_{n_1, n_2, n_3, n_4}^{t, c, c', p} \tag{1a}
\]

\[
\text{Cost}_{\text{total}} = \sum_{n_1, n_2, n_3, n_4} \sum_{t=1}^{T} \sum_{d=1}^{D} \sum_{k=1}^{K} \sum_{p=1}^{P} \text{OC}^{t, d, k, p}_{n_1, n_2, n_3, n_4} \cdot q_{n_1, n_2, n_3, n_4}^{t, d, k, p} + \sum_{n_1, n_2, n_3, n_4} \sum_{t=1}^{T} \sum_{c=1}^{C} \sum_{c'=1}^{C'} \sum_{p=1}^{P} \text{FOC}^{t, c, c', p}_{n_1, n_2, n_3, n_4} + \sum_{n_1, n_2, n_3, n_4} \sum_{t=1}^{T} \sum_{d=1}^{D} \sum_{k=1}^{K} \sum_{p=1}^{P} \text{FCC}^{t, d, k, p}_{n_1, n_2, n_3, n_4} \cdot q_{n_1, n_2, n_3, n_4}^{t, d, k, p} \tag{1b}
\]

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 Farrokh-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 \[ \text{OF}_2 = \sum_{m \in M} \sum_{d \in D} EF_m OM_{m}^{NT} + \sum_{c \in C} \sum_{d \in D} EF_c OM_{c}^{NT} + \sum_{n \in N} \sum_{c \in C} \sum_{d \in D} EP_{m,n} Q_{m,n}^{s,t} + \sum_{n \in N} \sum_{m \in M} \sum_{p \in P} ES_{d,p}^n H_{d,p}^{s,t} \]
\[ + \sum_{n \in N} \sum_{m \in M} \sum_{c \in C} \sum_{d \in D} EC_{c,p}^n f_{n}^{s,t} + \sum_{n \in N} \sum_{m \in M} \sum_{c \in C} \sum_{d \in D} ET_{s,m,p}^n f_{n}^{s,t} \]
\[ + \sum_{n \in N} \sum_{p \in P} \sum_{d \in D} ET_{m,d,p} f_{n}^{s,t} + \sum_{n \in N} \sum_{p \in P} \sum_{d \in D} ET_{k,d,k,p} f_{n}^{s,t} \]
\[ + \sum_{n \in N} \sum_{p \in P} \sum_{d \in D} ET_{c,d,c,p} f_{n}^{s,t} + \sum_{n \in N} \sum_{p \in P} \sum_{d \in D} ET_{c,c,p} f_{n}^{s,t} \]

\[(2)\]

2-2-2- Constraints

\[ \sum_{p \in P} f_{m,p}^{n,t} = \rho_{p} Q_{m,p}^{n,t} \quad \forall m, p', n > 0, t \]
\[ (3)\]

\[ Q_{m,p}^{n,t} = \sum_{d \in D} f_{m,d,p}^{n,t} \quad \forall m, p, n > 0, t \]
\[ (4)\]

\[ H_{d,p}^{n,t} + \sum_{m \in M} f_{m,d,p}^{n,t} = H_{d,p}^{n,t} + \sum_{k \in K} f_{d,k,p}^{n,t} \quad \forall d, p, n, t \neq 1 \]
\[ (5)\]

\[ H_{d,p}^{n,T} + \sum_{m \in M} f_{m,d,p}^{n,T} = H_{d,p}^{n,T} + \sum_{k \in K} f_{d,k,p}^{n,T} \quad \forall d, p, n, t = 1 \]
\[ (6)\]

\[ \sum_{c \in C} f_{c,p}^{n,t} = \sum_{c \in C} f_{c,c,p}^{n,t} \quad \forall c, p, n > 0, t \]
\[ (7)\]

\[ \sum_{d \in D} f_{d,k,p}^{n,t} = \text{Dem}_{d,k,p}^{n,t} \quad \forall p, n > 0, t \]
\[ (8)\]

\[ \sum_{c \in C} f_{c,p}^{n,t} \leq \sum_{d \in D} f_{d,k,p}^{n,t} \]
\[ (9)\]

\[ OM_{m}^{n} \geq OM_{m}^{n-1} \quad \forall m, n > 0 \]
\[ (10)\]

\[ OD_{d}^{n} \geq OD_{d}^{n-1} \quad \forall d, n > 0 \]
\[ (11)\]

\[ OC_{c}^{n} \geq OC_{c}^{n-1} \quad \forall c, n > 0 \]
\[ (12)\]

\[ \sum_{m \in M} FO_{m}^{n} (OM_{m}^{n-1} - OM_{m}^{n}) + \sum_{d \in D} FO_{d}^{n} (OD_{d}^{n-1} - OD_{d}^{n}) \]
\[ + \sum_{c \in C} FO_{c}^{n} (OC_{c}^{n-1} - OC_{c}^{n}) + \sum_{n \in N} \sum_{c \in C} \sum_{d \in D} FAM_{n,c}^{n} (O_{n,c}^{n-1} - O_{n,c}^{n}) \leq B^{n} \]
\[ (13)\]

\[ \sum_{n \in N, o \in O} O_{m,o}^{n} \leq OM_{m}^{n} \quad \forall m, n > 0 \]
\[ (14)\]

\[ UC_{m}^{n} = \sum_{n \in N} \sum_{a \in A_{m}} \sum_{o \in O} Exp_{m,a,o}^{n} \quad \forall m, n > 0 \]
\[ (15)\]

\[ \sum_{p \in P} Ur_{m,p,n}^{o,t} \leq UC_{m}^{n} \quad \forall m, n > 0, t \]
\[ (16)\]

\[ UC_{m}^{n} \leq Cap_{m}^{\max} OM_{m}^{n} \quad \forall m, n > 0 \]
\[ (17)\]

\[ \sum_{p \in P} Ur_{p}^{n,t} H_{d,p}^{n,t} + \frac{1}{2} \sum_{m \in M} \sum_{p \in P} Ur_{p}^{n,t} f_{m,p}^{n,t} \leq OD_{d}^{n} Cap_{d}^{\max} \quad \forall d, n > 0, t \]
\[ (18)\]
\[
\sum_{k \in K} \sum_{p \in P} f_{k,p}^{n,t} \leq OC_{c}^{n} Cap_{c}^{\text{max}} \quad \forall c, n > 0, t
\]  
(19)

\[
OM_{m}^{n,t}, O_{m}^{n,t}, O_{m,o}^{n,t} = \{0,1\}
\]

\[
Q_{m,p,p}^{n,t}, f_{s,m,p}, f_{s,j,p}^{n,t}, s_{k,p j}, PR_{k,p}^{n,t}, IPR_{k,p}^{n,t}, UB_{n} \geq 0
\]  
(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

\[
Dem_{r,k,p}^{n,t} = Demand_{r,k,p}^{n,t} - \alpha_{r,k,p} PR_{r,k,p}^{n,t} + \alpha'_{r,k,p} IPR_{r,k,p}^{n,t}
\]  
(21)

Where \( PR_{r,k,p}^{n,t} \) and \( IPR_{r,k,p}^{n,t} \) 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.

\[
Re_{r,k,p}^{n,t} = \theta_{r,k,p} Demand_{r,k,p}^{n,t} - \beta_{r,k,p} IPR_{r,k,p}^{n,t} + \beta'_{r,k,p} IPR_{r,k,p}^{n,t}
\]  
(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.

\[
\Pi_{r,k,p}^{n,t} = \left( PR_{r,k,p}^{n,t} - C_{r,k,p}^{n,t} \right) \left( Dem_{r,k,p}^{n,t} \right) + \left( SV_{r,c,p}^{n,t} - IPR_{r,k,p}^{n,t} \right) \left( Re_{r,k,p}^{n,t} \right)
\]  
(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.

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<td>- Storage</td>
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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.

\[
\frac{\partial \Pi^{s,i}_{r,k,p}}{\partial PR^{s,i}_{r,k,p}} = Demand^{s,i}_{r,k,p} - 2\alpha^{s,i}_{r,k,p}PR^{s,i}_{r,k,p} + \alpha'_{r,k,p}PR^{s,i}_{r,k,p} + \alpha_{r,k,p}C^{s,i}_{r,k,p}
\]

\[
\frac{\partial \Pi^{i,p}_{r,k,p}}{\partial IPR^{i,p}_{r,k,p}} = \beta^{r,k,p}IPR^{i,p}_{r,k,p} - 2\beta^{r,k,p}IPR^{i,p}_{r,k,p} - \theta^{r,k,p}Demand^{i,p}_{r,k,p} + \beta^{r,k,p}SV^{i,p}_{r,k,p}
\]

\[
\frac{\partial^2 \Pi^{s,i}_{r,k,p}}{\partial PR^{s,i}_{r,k,p}^2} = -2\alpha^{s,i}_{r,k,p}
\]

\[
\frac{\partial^2 \Pi^{i,p}_{r,k,p}}{\partial PR^{i,p}_{r,k,p}^2} = 0
\]

\[
\frac{\partial^2 \Pi^{s,i}_{r,k,p}}{\partial IPR^{i,p}_{r,k,p}^2} = -2\beta^{r,k,p}
\]
\[
\frac{\partial^2 \Pi_{r,k,p}^{\alpha_f}}{\partial IPR_{r,k,p} \partial PR_{r,k,p}^{\alpha_f}} = 0
\]

(29)

The Hessian matrix can be calculated using equation 30.

\[
H = \begin{bmatrix}
-2\alpha_{r,k,p} & 0 \\
0 & -2\beta_{r,k,p}
\end{bmatrix}
\]

(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.

\[
\frac{\partial \Pi_{r,k,p}^{\alpha_f}}{\partial PR_{r,k,p}^{\alpha_f}} = Demand_{r,k,p}^{\alpha_f} - 2\alpha_{r,k,p}PR_{r,k,p}^{\alpha_f} + \alpha_{r,k,p}'PR_{r,k,p}^{\alpha_f} + \alpha_{r,k,p}c_{r,k,p} = 0
\]

(31)

\[
\frac{\partial \Pi_{r,k,p}^{\alpha_f}}{\partial IPR_{r,k,p}} = \beta_{r,k,p}'IPR_{r,k,p} - 2\beta_{r,k,p}'IPR_{r,k,p} - \theta_{r,k,p} Demand_{r,k,p}^{\alpha_f} + \beta_{r,k,p} SV_{r,k,p} = 0
\]

(32)

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

\[
PR_{r,k,p}^{\alpha_f} = \frac{\alpha_{r,k,p}'Demand_{r,k,p}^{\alpha_f} + 2\alpha_{r,k,p}' \left( Demand_{r,k,p}^{\alpha_f} + \alpha_{r,k,p}c_{r,k,p} \right) + \alpha_{r,k,p}' \alpha_{r,k,p}' c_{r,k,p} \alpha_{r,k,p}'}{4\alpha_{r,k,p}' \alpha_{r,k,p}' - \alpha_{r,k,p}' \alpha_{r,k,p}'}
\]

(33)

\[
IPR_{r,k,p} = \frac{\beta_{r,k,p}' \beta_{r,k,p}' SV_{r,k,p} + 2\beta_{r,k,p}' \beta_{r,k,p}' SV_{r,k,p} - 2\beta_{r,k,p}' \theta_{r,k,p} SV_{r,k,p} - \beta_{r,k,p}' \theta_{r,k,p} Demand_{r,k,p}^{\alpha_f} - \beta_{r,k,p}' \theta_{r,k,p} Demand_{r,k,p}^{\alpha_f}}{4\beta_{r,k,p}' \beta_{r,k,p}' - \beta_{r,k,p}' \beta_{r,k,p}'}
\]

(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 \( OF(\bar{x}) = [OF_1(\bar{x}),...,OF_m(\bar{x})] \) with respect to multiple constraints such as \( g_i(\bar{x}) \leq 0, \quad i = 1,2, ..., c, \ \bar{x} \in X \), where \( x \) is the solution vector and \( X \) is the feasible region. In a maximization form, the domination of solution \( \bar{a} \) to solution \( \bar{b}(\bar{a}, \bar{b} \in X) \) can be described as follows:

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

2) \( \exists i \in [1, 2, ..., m] : f_i(\bar{a}) > f_i(\bar{b}) \)

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](image)

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.

\[
Power_i = \left( \sum_{j=1}^{D} OF_j(i) \right)^{-1} \left( \sum_{j=1}^{D} OF_j(i) \right)^{-1} \left( \sum_{j=1}^{D} \left( OF_j(i) \right)^{-1} \right)^{-1} \left( Rank(C) - 1 \right) \times D
\]  

(35)

Where \( D \) is the number of objective functions \( OF_j(i) \) is value of the \( j \)th 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:
\[ NC_n = \text{round}\left\{ \frac{p_n N_{\text{col}}}{N} \right\} \]  

Where \( p_n = \frac{\text{power}_n}{\sum_{i=1}^{N} \text{power}_i} \), 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.
  
  \[ x \sim U(0, \beta \times d) \]  
  \[ \theta \sim U(-\gamma, \gamma) \]  

Where \( U(.) \) is a random variable with Uniform distribution function, \( d \) indicates the distance among colony and its imperialist and \( \beta \) and \( \gamma \) 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.
  
  \[ TC_n = \text{Cost(imperialist)}_n + \zeta \text{mean}\{\text{cost}\{\text{colonies}\}\} \]  

Where \( \zeta \) 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 \( (\text{NTC}_n) \), equation 40 is used.
  
  \[ \text{NTC}_n = TC_n - \max\{TC\} \]  

- **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).
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.
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>
<thead>
<tr>
<th>Problem No.</th>
<th>Supply chain</th>
<th>PR</th>
<th>Dem</th>
<th>IPR</th>
<th>Ret</th>
<th>T1</th>
<th>OF1</th>
<th>OF2</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>New entrant SC</td>
<td>1177.8</td>
<td>1849</td>
<td>46.97</td>
<td>911</td>
<td>1255777</td>
<td>9737687</td>
<td>1526232</td>
</tr>
<tr>
<td>P1</td>
<td>Existing SC</td>
<td>1462.2</td>
<td>1924</td>
<td>64.51</td>
<td>989</td>
<td>2054594</td>
<td>23433371</td>
<td>2811082</td>
</tr>
<tr>
<td>P2</td>
<td>New entrant SC</td>
<td>1258.1</td>
<td>1908</td>
<td>10.44</td>
<td>1071</td>
<td>1587530</td>
<td>38123554</td>
<td>5441700</td>
</tr>
<tr>
<td>P2</td>
<td>Existing SC</td>
<td>1105.7</td>
<td>1696</td>
<td>29.97</td>
<td>1053</td>
<td>1323721</td>
<td>43783893</td>
<td>6925080</td>
</tr>
<tr>
<td>P3</td>
<td>New entrant SC</td>
<td>1070.7</td>
<td>1794</td>
<td>28.45</td>
<td>977</td>
<td>1375879</td>
<td>23433371</td>
<td>2811082</td>
</tr>
<tr>
<td>P3</td>
<td>Existing SC</td>
<td>1058.2</td>
<td>1697</td>
<td>63.11</td>
<td>1066</td>
<td>1329581</td>
<td>43783893</td>
<td>6925080</td>
</tr>
<tr>
<td>P4</td>
<td>New entrant SC</td>
<td>1103.1</td>
<td>1660</td>
<td>62.45</td>
<td>1045</td>
<td>1098345</td>
<td>150926132</td>
<td>71214097</td>
</tr>
<tr>
<td>P4</td>
<td>Existing SC</td>
<td>1215.4</td>
<td>1788</td>
<td>39.83</td>
<td>1068</td>
<td>1549302</td>
<td>42904860</td>
<td>12743575</td>
</tr>
<tr>
<td>P5</td>
<td>New entrant SC</td>
<td>1013.7</td>
<td>1406</td>
<td>67.99</td>
<td>1044</td>
<td>820155</td>
<td>42904860</td>
<td>12743575</td>
</tr>
<tr>
<td>P5</td>
<td>Existing SC</td>
<td>1104.1</td>
<td>1760</td>
<td>53.05</td>
<td>913</td>
<td>1486366</td>
<td>57489721</td>
<td>22894046</td>
</tr>
<tr>
<td>P6</td>
<td>New entrant SC</td>
<td>1114.9</td>
<td>1544</td>
<td>37.73</td>
<td>1049</td>
<td>1070500</td>
<td>57489721</td>
<td>22894046</td>
</tr>
<tr>
<td>P6</td>
<td>Existing SC</td>
<td>889.4</td>
<td>1557</td>
<td>57.37</td>
<td>970</td>
<td>841900</td>
<td>80564936</td>
<td>45914352</td>
</tr>
<tr>
<td>P7</td>
<td>New entrant SC</td>
<td>1425</td>
<td>1670</td>
<td>66</td>
<td>1359</td>
<td>2445469</td>
<td>87667503</td>
<td>59345081</td>
</tr>
<tr>
<td>P7</td>
<td>Existing SC</td>
<td>944</td>
<td>1519</td>
<td>68</td>
<td>1146</td>
<td>1550214</td>
<td>150926132</td>
<td>71214097</td>
</tr>
<tr>
<td>P8</td>
<td>New entrant SC</td>
<td>1204.6</td>
<td>1692</td>
<td>59.65</td>
<td>1081</td>
<td>1300449</td>
<td>87667503</td>
<td>59345081</td>
</tr>
<tr>
<td>P8</td>
<td>Existing SC</td>
<td>949.7</td>
<td>1663</td>
<td>61.04</td>
<td>1027</td>
<td>952741</td>
<td>150926132</td>
<td>71214097</td>
</tr>
<tr>
<td>P9</td>
<td>New entrant SC</td>
<td>1156.6</td>
<td>1447</td>
<td>66.86</td>
<td>839</td>
<td>1010727</td>
<td>150926132</td>
<td>71214097</td>
</tr>
<tr>
<td>P9</td>
<td>Existing SC</td>
<td>943.6</td>
<td>1596</td>
<td>51.69</td>
<td>918</td>
<td>938654</td>
<td>265507330</td>
<td>86486845</td>
</tr>
</tbody>
</table>

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.

Table 3. Competitive stage’s results
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>
<thead>
<tr>
<th>Pareto solution No.</th>
<th>Objective Function 1</th>
<th>Objective Function 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62467509</td>
<td>24032438</td>
</tr>
<tr>
<td>2</td>
<td>52819794</td>
<td>22239681</td>
</tr>
<tr>
<td>3</td>
<td>60520857</td>
<td>23428987</td>
</tr>
<tr>
<td>4</td>
<td>59966710</td>
<td>23253986</td>
</tr>
<tr>
<td>5</td>
<td>57551143</td>
<td>22730255</td>
</tr>
<tr>
<td>6</td>
<td>56674397</td>
<td>22601808</td>
</tr>
<tr>
<td>7</td>
<td>53902955</td>
<td>22371966</td>
</tr>
<tr>
<td>8</td>
<td>56014400</td>
<td>22493244</td>
</tr>
</tbody>
</table>
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 \( \text{Dem}_{r,k,p} \) and selling prices \( PR_{r,k,p} \). 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 \( PR_{r,k,p} \) and market share \( \text{Dem}_{r,k,p} \). 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 \( IPR_{r,k,p} \) and the amount of returned product \( \text{Re}_{r,k,p} \) 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.

![Graph](image)

**Fig 7.** Variations of economic OF vs. selling price’s elasticity 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
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.

References


