



Considering Pricing Problem in a Dynamic and Integrated Design of Sustainable Closed-loop Supply Chain Network

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KEYWORDS

Supply Chain Network Design, Sustainability, Long-term and Short-term Decisions, e-constraint Method, Imperialist Competitive Algorithm

ABSTRACT

Flexible and dynamic supply chain network design problem has been studied by many researchers during past years. Since integration of short-term and long-term decisions in strategic planning leads to more reliable plans, in this paper a multi-objective model for a sustainable closed-loop supply chain network design problem is proposed. The planning horizon of this model contains multiple strategic periods so that the structure of supply chain can be changed dynamically during the planning horizon. Furthermore, in order to have an integrated design, several short-term decisions are considered besides strategic network design decision. One of these short-term decisions is determining selling price and buying price in the forward and reverse logistics of supply chain, respectively. Finally, an augmented e-constraint method is used to transform the problem to a single-objective model and an imperialist competitive algorithm is presented to solve large scale problems. The results' analysis indicates the efficiency of the proposed model for the integrated and dynamic supply chain network design problem.

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1. Introduction

The supply chain can be considered as a combination of different organizations which serve customers in cooperation with each other. Making coordination among these different members and planning in the supply chain is one of the main issues of supply chain management (SCM) [1]. Considering the time horizon, the planning in SCM can be categorized into strategic, tactical, and operational levels [2]. In contrast with tactical and operational decisions, the strategic planning in SCM contains decisions with long-lasting influence on supply chain [3].

Among different strategic decisions, supply chain network design (SCND) can be regarded as an essential decisions made in SCM [3-4]. In a SCND problem the main issue is finding an efficient infrastructure for the entire supply chain so that the flow of goods and communication between different members of a supply chain can be done, simply. Expensive nature of changing the structure of a supply chain makes SCND problem as a strategic decision in SCM [1, 3, 5]. In addition to network design of supply chain, the other long-term decisions such as defining capacity and technology of facilities can be referred [6].

In order to adapt to changing environment, many managers are interested in designing the network of a supply chain dynamically so that the structure of supply chain can be changed with

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respect to the variations of the market. So, many researchers considered dynamic supply chain network design in the recent years [7]. It also should be noted that based on the interactions existing among long-term and short-term decisions and the effects of these decisions on each other, many supply chain managers consider tactical and operational decisions besides the strategic supply chain network design problem. One of these short-term decisions, less regarded in the literature of SCND problem, is pricing.

In the recent years, improving attentions to environmental concern, increasing resistance with polluting activities, governmental legislations associated with social issues, and etc make many firms to concentrate on other goals as well as their economic goals. Hence, during the last decade, sustainability, as a new concept in which environmental and social concerns are regarded, entered different scopes of the supply chain such as SCND problem, besides economic destinations [8].

Accordingly, the aim of this paper is proposing a more comprehensive model for a dynamic and integrated closed-loop supply chain network design problem in which environmental, social and economic concerns are regarded, simultaneously. For sake of dynamism and integration of network design, several strategic periods are considered where each of these strategic periods consists of multiple short-term periods in which tactical and operational decisions should be defined. The selling price of products to customer zones and buying price of used products from customer zones are two of these short-term decisions. Finally, the proposed supply chain network design problem is formulated as a multi-objective mixed-integer linear planning (MILP) model. The contributions of this paper can be summarized as follow:

- Considering multiple strategic periods to make the dynamic design of supply chain possible.
- Considering selling price of products using linear demand functions in forward logistics of the supply chain.
- Considering buying price of used products in reverse logistics of supply chain using linear acquisition function.
- Proposing a leveling approach for pricing decisions in forward and reverse logistics to have a MILP model which simplifies solving the proposed model.

Practically, the proposed model can help supply chains in several aspects to design their networks

more efficient. On one side, this model makes changing the structure of supply chain possible respecting several long-term and strategic periods. This helps managers to adapt their supply chain to the changing competitive market. On the other side, integration of long-term and short-term decisions can lead to more realistic planning, because defining the structure of a supply chain without respecting tactical and operational decisions and their interactions is not possible, truly. The proposed model also encourages the customers to return used products to supply chain using consideration of incentive buying price for used products by which both economic and environmental goals of supply chain can be affected positively. Finally, the consideration of sustainability in the supply chain network design problem helps managers to achieve a better situation in a competitive market. The rest of this paper is organized as follows: the literature related to SCND problem is reviewed in Section 2. The closed-loop supply chain network design problem is defined in Section 3 and a MILP model is used to formulate this problem. The solution approach of the proposed model is stated in this Section, too. In Section 4, the results of solving the model for a numerical example and sensitivity analysis on parameters are presented. Finally, the conclusion and future research suggestions are given in Section 5.

2. Literature Review

The SCND problem has been widely studied by many researchers through recent years [2, 6]. Accordingly, the related literature can be categorized with respect to different aspects, as shown in Figure 1.

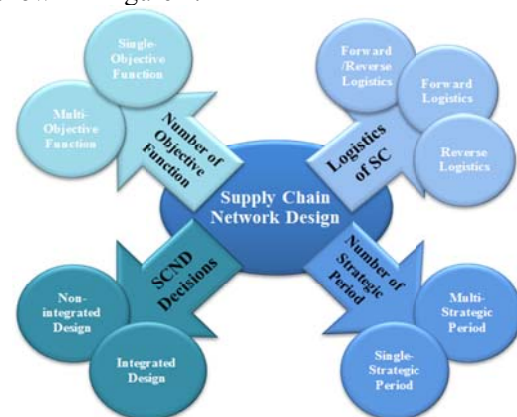


Fig. 1. Classification of SCND literature

The SCND problem has been widely studied by many researchers through recent years [2, 6]. Accordingly, the related literature can be

categorized with respect to different aspects, as shown in Figure 1.

2-1. Based on supply chain logistics

The first group includes researches which have considered forward logistics in SCND problem [9-17]. In contrast, the second group consists of researches in which the reverse logistics of the supply chain is considered solely in SCND [18-22]. The last group regarded both forward and reverse logistics simultaneously in SCND problem [23-32]. It should be noted that in the recent years the reverse logistics have been attended in the studies because of the importance of environmental issues [33]. For a more comprehensive study in this area, one can refer to [34].

2-2. Based on number of objective functions

In this manner, the literature of SCND can be categorized into two groups. The first one studied single objective SCND problem which includes more than ninety percent of related researches [2]. The second group includes researches which consider multi-objective models for SCND problem. For a more comprehensive study in this area, one can refer to [5].

One of the main concepts has been attended widely in the literature of SCND problem is sustainability [35-36]. Based on [37], most of researches, studied the sustainable SCND problem, considering only economic and environmental concerns [11, 17, 23, 26, 27, 32, 35], while social concerns have been considered only by a few researches [14, 20, 29, 31]. For a more comprehensive study in the sustainable SCND problem, one can refer to [34].

2-3. Based on number of strategic periods

The first group includes researches which evaluated SCND problem through a single strategic period in which the changes of the network is not possible [7]. In contrast, the second group contains researches in which the structure of supply chain can be varied during multiple strategic periods [14, 17, 26, 28, 31, 39].

2-4. Based on decisions' time horizon

The first researches of SCND problem investigated only strategic and long-term decision in designing the supply chain network. In contrast, the second group considered integrated SCND problem in which tactical and operational decisions are also regarded besides strategic and long-term decisions. A comprehensive study has been presented by [40].

Among studies which presented integrated SCND problem, only a few ones (such as [41]) considered multiple strategic and tactical periods, simultaneously. The model presented in [41], developed by several researchers [7, 13].

Some researchers considered pricing decisions in forward logistics network design [6, 8, 9, 14, 15]. The buying price-dependent acquisition functions in reverse logistics have been considered by several researchers, too [18, 19, 24, 25, 28]. Only a few works considered pricing decisions in forward and reverse logistics, simultaneously [30].

As indicated in Table 1, only a few researches investigated the SCND problem dynamically and through several strategic periods. While respecting the changing environment, the unchangeable and static design of a supply chain can gradually lead to the failure of supply chain in the competitive market. It can also be observed in Table 1 that few researches considered pricing decisions in forward and reverse logistics simultaneously. This paper attempts to present a more comprehensive model for a dynamic SCND problem in which tactical and operational decisions such as pricing have been integrated with strategic decisions. Also, the presented leveling approach for selling and buying price simplifies the mathematical model.

3. Problem Definition

In this paper, the network design problem of a closed-loop supply chain which aims to enter the market of selling some products is considered. The configuration of this supply chain is indicated in Figure 2. In forward logistics of this supply chain, manufacturers provide their raw material from suppliers and produce multiple products. Then, these products are transported to customer zones via distribution centers. In reverse logistics, collection centers collect used products from customer zones and transport them to recovery centers which investigate used products and categorize them to recoverable and unrecoverable products. The first group will be recovered and transported to distribution centers again while the later will be transported to disposal centers.

Tab. 1. Literature of SCND problem

Ref	Logistics of Supply Chain	Number of Objective Functions	Sustainability Concerns			Number of Tactical and Strategic Periods		Model	Decision Variables								Solution Approach	
			Economic	Environmental	Social	Multiple Tactical Period	Multiple Strategic Period		Strategic			Tactical						
									Location	Technology	Capacity	Supplier Selection	Production	Assignment/ Shipment	Storage	Selling Price		Buying Price
[8]	FL	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>									HA
[9]	FL	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>									HA
[21]	CLSC	2	<input type="checkbox"/>	<input type="checkbox"/>				MILP	<input type="checkbox"/>				<input type="checkbox"/>					HA
[17]	RL	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>									MH
[18]	RL	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>									MH
[19]	RL	>2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			MILP	<input type="checkbox"/>									MH
[10]	FL	2	<input type="checkbox"/>	<input type="checkbox"/>				MILP	<input type="checkbox"/>	<input type="checkbox"/>				<input type="checkbox"/>				LM
[22]	CLSC	1	<input type="checkbox"/>					NLP								<input type="checkbox"/>	<input type="checkbox"/>	HA
[23]	CLSC	1	<input type="checkbox"/>					NLP									<input type="checkbox"/>	LM
[20]	RL	2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			MILP	<input type="checkbox"/>	<input type="checkbox"/>								MH
[11]	FL	2	<input type="checkbox"/>		<input type="checkbox"/>			MILP	<input type="checkbox"/>									e-CM
[24]	CLSC	2	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>		MILP	<input type="checkbox"/>				<input type="checkbox"/>					CS
[25]	CLSC	2	<input type="checkbox"/>	<input type="checkbox"/>				MIP	<input type="checkbox"/>									e-CM
[12]	FL	1	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>	MILP	<input type="checkbox"/>		<input type="checkbox"/>				<input type="checkbox"/>			LM
[26]	CLSC	1	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>	MILP	<input type="checkbox"/>		<input type="checkbox"/>				<input type="checkbox"/>			CS
[13]	FL	>2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		MILP	<input type="checkbox"/>									e-CM
[27]	CLSC	>2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>			MILP	<input type="checkbox"/>	<input type="checkbox"/>								MH
[14]	FL	1	<input type="checkbox"/>					MILP	<input type="checkbox"/>								<input type="checkbox"/>	LM
[15]	FL	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>								<input type="checkbox"/>	LM
[6]	FL	1	<input type="checkbox"/>			<input type="checkbox"/>	<input type="checkbox"/>	MILP	<input type="checkbox"/>	<input type="checkbox"/>							<input type="checkbox"/>	MH
[28]	CLSC	1	<input type="checkbox"/>					MINLP	<input type="checkbox"/>								<input type="checkbox"/>	H
[22]	CLSC	>2	<input type="checkbox"/>	<input type="checkbox"/>				MINLP	<input type="checkbox"/>									MH
[16]	FL	2	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>		MILP	<input type="checkbox"/>	<input type="checkbox"/>								MH
[29]	CLSC	>2	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		MILP	<input type="checkbox"/>		<input type="checkbox"/>							CS
[31]	CLSC	2	<input type="checkbox"/>	<input type="checkbox"/>				MILP	<input type="checkbox"/>									CS
Current paper	CLSC	>2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	MILP	<input type="checkbox"/>		<input type="checkbox"/>						<input type="checkbox"/>	e-CM

HA: Heuristic Approach

MH: Meta-heuristic Approach

LM: Lagrangian Method

CS: Commercial Solver

e-CM: E-Constraint Method

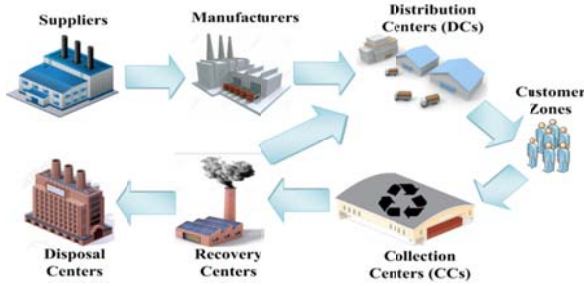


Fig. 2. Configuration of closed-loop supply chain network

In this paper, it is assumed that in addition to new entrant supply chain there is an existing supply chain which sells the same products in customer zone and achieves a portion of the market share, consequently. Regarding this existing supply chain, the new entrant supply chain can achieve only a specified portion of demands.

To integrate short-term and long-term decisions, it is assumed that the planning horizon consists of several strategic periods so that each strategic period includes multiple tactical periods (as shown in Figure 3).

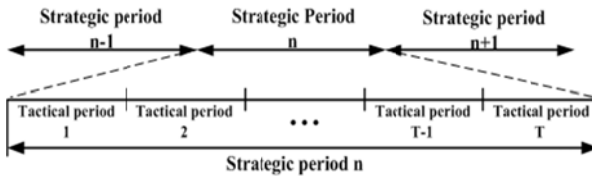


Fig. 3. Relationship among strategic and tactical period

It is also assumed that a specified budget is assigned to each strategic period which can be

expensed in order to improve the structure of supply chain and the remained budget can be invested with a determined interest rate.

The aim of this network design problem is finding an efficient infrastructure for supply chain so that the profit of supply chain is maximized, the number of unreturned used products is minimized, and job opportunities created by the supply chain are maximized.

The other assumptions of this SCND problem are as follows:

- The potential locations for facilities are determined.
- Opened facilities cannot be closed during next strategic periods.
- The potential options for improving the capacity of manufacturers are determined.
- The demand function for each product depends linearly on selling price.
- The acquisition function for each used product depends linearly on buying price.
- The shortage can occur as lost sales.
- Recovered products in recovery centers can be received by distribution center after one tactical period.
- All the parameters considered in forward and reverse logistics are deterministic.

3-1. Notations

Table 2 indicates all notations, parameters, and decision variables used in the proposed mathematical model.

Tab. 2. Notations, parameters and decision variables

<p><i>Sets</i> <i>S</i>: Suppliers ($s \in S$) <i>M</i>: Manufacturers ($m \in M$) <i>D</i>: Distribution centers ($d \in D$) <i>K</i>: Customer zones ($k \in K$) <i>C</i>: Collection centers ($c \in C$) <i>R</i>: recovery centers ($r \in R$) <i>C'</i>: Disposal centers ($c' \in C'$) <i>P'</i>: Raw materials ($p' \in P'$) <i>P</i>: Products ($p \in P$) <i>L</i>: Level of selling price ($l \in L$) <i>L'</i>: Level of Buying price ($l' \in L'$) <i>O</i>: Capacity options for manufacturers ($o \in O$) <i>N</i>: Number of strategic periods ($n \in N$) <i>T</i>: Number of tactical periods ($t \in T$) <i>Parameters</i> <i>FO_iⁿ</i>: Fixed cost charged in strategic period</p>	<p><i>Exp_{m,o}</i>: Capacity expansion of capacity option <i>o</i> at manufacturer <i>m</i>, <i>Cap_m^{max}</i>: Maximum installable production capacity of manufacturer <i>m</i>, <i>Cap_d^{max}</i>: Maximum storage capacity of distribution center <i>d</i>, <i>Cap_c^{max}</i>: Maximum collecting capacity of collection center <i>c</i>, <i>Cap_r^{max}</i>: Maximum recovery capacity of recovery center <i>r</i>, <i>U_m</i>: Utilization rate of manufacturer <i>m</i>, <i>B_n</i>: Assigned budget for strategic periods <i>n</i>, <i>IR_n</i>: Interest rate of investing in Strategic periods <i>n</i>, <i>ρ_{p'p}</i>: Quantity of required raw material <i>p'</i> to</p>
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<p>$n-1$ for opening facility 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, $FCC_{m,o}^n$: Fixed cost of manufacturer m to operate under capacity option o in strategic period n, FOC_i : Fixed operating cost of facility i, $PC_{m,p}$: 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, $IC_{r,p}$: Variable cost of inspecting one unit of product p at recovery center r, $RC_{r,p}$: Variable cost of recovering one unit of product p at recovery center r, $SC_{k,p}$: Variable cost of shortage 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, $BC_{sp'}$: Buying cost of one unit of raw material p' from supplier s, J_i : Number of job opportunities created due to opening facility i,</p>	<p>produce one unit of product p, Ur_p : Usage rate of storage capacity for distribution center to store one unit of product p, $Ur_{m,p}$: Usage rate of production capacity for manufacturer m to produce one unit of product p, $A_{m,d}$: Number of deliveries from manufacturer m to distribution center d, $A_{r,d}$: Number of deliveries from recovery center r to distribution center d, $\alpha_{k,p}$: Return rate of used product p, collected free and without buying from customer zone k, $\beta_{k,p}$: Elasticity coefficient of selling price in demand function of customer zone k for product p, $\beta_{k,p}^r$: Elasticity coefficient of buying price in acquisition function of customer zone k, for product p, γ_p : Recoverable fraction of returned product p, $Pr_{k,p}^{n,t}$: Selling price of product p to customer zone k in tactical period t of strategic period n, $Pr_{k,p,l}^{n,t}$: Selling price of product p to customer zone k at price level l in tactical period t of strategic period n, ω : Percentage of market share for existing supply chain, $Demand_{k,p}^{n,t}$: Potential demand of customer zone k for product p in tactical period t of strategic period n,</p>
<p>$MaxDem_{k,p}^{n,t}$: Maximum achievable market share of customer zone k for product p in tactical period t of strategic period n, $Dem_{k,p}^{n,t}$: Demand of customer zone k, related to entrant supply chain, for product p in tactical period t of strategic period n, $Dem_{k,p,l}^{n,t}$: Demand of customer zone k, related to entrant supply chain, for product p in tactical period t of strategic period n based on selling price level l, $IPr_{k,p,l'}^{n,t}$: Buying price of product p in customer zone k at price level l' in tactical period t of strategic period n, $Ret_{k,p,l'}^{n,t}$: The amount of returned product p from customer zone k in tactical period t of strategic period n based on incentive price level l', Decision variables OM_m^n : 1 if manufacturer m is open during</p>	<p>product m to customer zone k in tactical period t of strategic period n, $\varphi_{k,p,l'}^{n,t}$: 1 if buying price level l' is used for buying additional used product m from customer zone k in tactical period t of strategic period n, $Q_{m,p}^{n,t}$: 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, $S_{k,p,l}^{n,t}$: Shortage of product p based on price level l in customer zone k in tactical period t of</p>

<p>strategic period n, OD_d^n : 1 if distribution center d is open during strategic period n, OC_c^n : 1 if collection center c is open during strategic period n, OR_r^n : 1 if recovery center r is open during strategic period n, $O_{m,o}^n$: 1 if capacity option o is installed at manufacturer m in strategic period n, $\mathcal{E}_{k,p,l}^{n,t}$: 1 if selling price level l is used for selling</p>	<p>strategic period n, UB_n : Unspent budget in strategic period n, SB_n : Spent budget in strategic period n to extend the network of supply chain, $Cost_{Fixed}$: Total operational fixed cost of supply chain, $Cost_{Var}$: Total operational variable cost of supply chain, $Cost_{total}$: Total cost of supply chain, $Income_{total}$: Total income of supply chain,</p>
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3-2. Selling price-dependent demand function

In the last decades, various price-dependent demand functions have been introduced in the literature. In this paper, one of the most common demand functions is used to consider the

relationship among demands and selling price of products. The used demand function can be formulated by Eq. (I) in which there is a linear relationship between demand and price. Figure 4(a) indicates this price-dependent demand function.

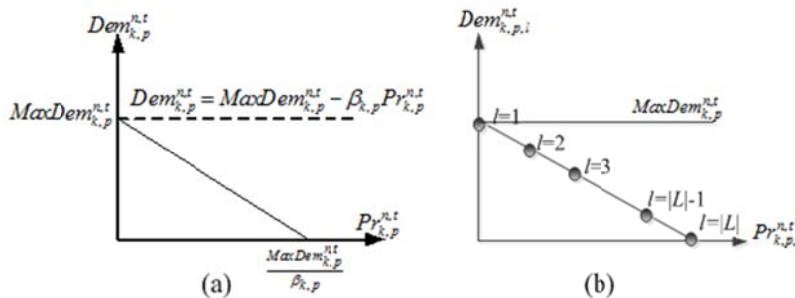


Fig. 4. Price-dependent demand function

$$Dem_{k,p}^{n,t} = (1 - \omega) Demand_{k,p}^{n,t} - \beta_{k,p} Pr_{k,p}^{n,t} = MaxDem_{k,p}^{n,t} - \beta_{k,p} Pr_{k,p}^{n,t} \tag{I}$$

Considering the existing supply chain, the new entrant can achieve only a portion of total demand ($Demand_{k,p}^{n,t}$) which equals $MaxDem_{k,p}^{n,t}$. The income of selling products to customer zones equals $Pr_{k,p}^{n,t} \sum_d f_{d,k,p}^{n,t}$ which makes a mixed-integer nonlinear programming (MINLP) model. Hence, in this paper in order to have a linear relationship among decision variables, a leveling approach similar to [7] is applied on selling price. In this manner, several discrete levels for selling price is considered in each customer zone, as shown in Figure 4(b). Assuming L as the number of price levels, the selling price for each level l , can be calculated by Eq. (II).

$$Pr_{k,p,l}^{n,t} = \frac{l-1}{L-1} \left(\frac{MaxDem_{k,p}^{n,t}}{\beta_{k,p}} \right) \tag{II}$$

So, the income of selling products for each price level equals $Pr_{k,p,l}^{n,t} (Dem_{k,p,l}^{n,t} \cdot \mathcal{E}_{k,p,l}^{n,t} - S_{k,p,l}^{n,t})$ which makes a MILP model.

3-3. Buying price-dependent acquisition function

In this paper, it is assumed that the number of returned products in reverse logistics depends linearly on buying price of used products which can be formulated by Eq. (III).

$$Ret_{k,p}^{n,t} = \alpha \sum_{d \in D} f_{d,k,p}^{n,t} + \beta_{k,p}^r IP_{k,p}^{n,t} \tag{III}$$

where $\alpha \sum_{d \in D} f_{d,k,p}^{n,t}$ indicates the total number of products returned free from customer zones and $\beta_{k,p}^r IP_{k,p}^{n,t}$ indicates the total number of bought products. Based on Eq. (III), it can be observed that increasing the buying price leads to increasing the number of returned products, as shown in Figure 5(a).

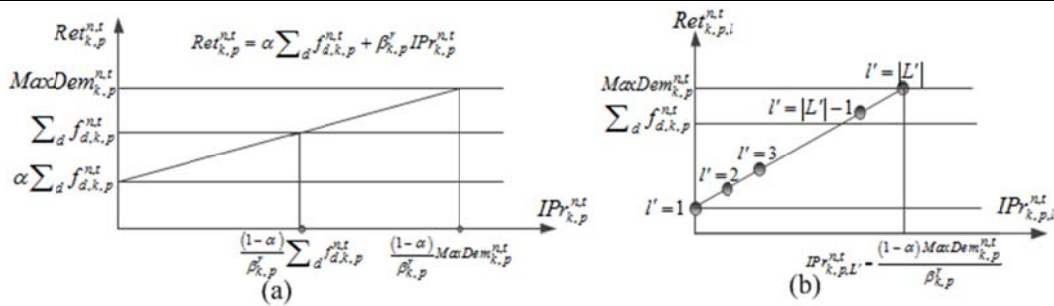


Fig. 5. Buying price-dependent acquisition function

According to mentioned acquisition function, the total cost of buying extra used products equals to $IP_{k,p}^{n,t} (\beta_{k,p}^r IP_{k,p}^{n,t})$ which leads to a MINLP model. The same as the mentioned approach for selling price (Section 3.2), a leveling approach is applied on buying price, as shown in Figure 5(b). Assuming L' as the total number of buying price levels, the buying price associated with level l can be calculated using Eq. (IV).

$$IP_{k,p,l}^{n,t} = \frac{l' - 1}{L' - 1} \left(\frac{(1 - \alpha) MaxDem_{k,p}^{n,t}}{\beta_{k,p}^r} \right) \quad (IV)$$

Finally, the total cost of buying products for each price level equals $IP_{k,p,l}^{n,t} (\beta_{k,p}^r IP_{k,p,l}^{n,t})$.

Since it is assumed that shortage can occur in customer zones, so Eq. (V) should be added to the proposed model as an extra constraint. This constraint prevents selecting buying prices which

$$Income_{total} = \sum_{n \in N} \sum_{t \in T} \left(\sum_{k \in K} \sum_{p \in P} \sum_{l \in L} Pr_{k,p,l}^{n,t} Dem_{k,p,l}^{n,t} \varepsilon_{k,p,l}^{n,t} - \sum_{k \in K} \sum_{p \in P} \sum_{l \in L} Pr_{k,p,l}^{n,t} S_{k,p,l}^{n,t} \right) \quad (1-1)$$

Total cost of supply chain includes fixed and variable costs which can be formulated by Eq. (1-2) and Eq. (1-3), respectively.

$$Cost_{Fixed} = \sum_{n \in N} \sum_{m \in M} FOC_m^n OM_m^n + \sum_{n \in N} \sum_{d \in D} FOC_d^n OD_d^n + \sum_{n \in N} \sum_{c \in C} FOC_c^n OC_c^n + \sum_{n \in N} \sum_{r \in R} FOC_r^n OR_r^n \quad (1-2)$$

$$Cost_{Var} = \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} BC_{s,p'}^n f_{s,m,p'}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{m \in M} \sum_{p \in P} PC_{m,p}^n Q_{m,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{d \in D} \sum_{p \in P} HC_{d,p} \left(H_{d,p}^{n,t} + \frac{1}{2} \sum_{m \in M} \frac{f_{m,d,p}^{n,t}}{A_{m,d}} + \frac{1}{2} \sum_{r \in R} \frac{f_{r,d,p}^{n,t}}{A_{r,d}} \right) + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{k \in K} \sum_{p \in P} \sum_{l \in L} SC_{k,p} S_{k,p,l}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{k \in K} \sum_{p \in P} \sum_{l' \in L'} \beta_{k,p}^r (IP_{k,p,l'}^{n,t})^2 \varphi_{k,p,l'}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{c \in C} \sum_{r \in R} \sum_{p \in P} (IC_{r,p} + RC_{r,p} \gamma_p) f_{c,r,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} TC_{s,m,p'} f_{s,m,p'}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{m \in M} \sum_{d \in D} \sum_{p \in P} TC_{m,d,p} f_{m,d,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{d \in D} \sum_{k \in K} \sum_{p \in P} TC_{d,k,p} f_{d,k,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{s \in S} \sum_{m \in M} \sum_{p' \in P'} TC_{k,c,p} f_{k,c,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{c \in C} \sum_{r \in R} \sum_{p \in P} TC_{c,r,p} f_{c,r,p}^{n,t} + \sum_{n > 0, n \in N} \sum_{t \in T} \sum_{r \in R} \sum_{d \in D} \sum_{p \in P} TC_{r,d,p} f_{r,d,p}^{n,t}$$

lead to returning used products more than satisfied demand.

$$\sum_{l' \in L'} \beta_{k,p}^r IP_{k,p,l'}^{n,t} \varphi_{k,p,l'}^{n,t} \leq (1 - \alpha) \sum_{d \in D} f_{d,k}^{n,t} \quad \forall k, p, n, t (V)$$

3-4. Mathematical model

The objective functions and constraints of the proposed model are as follows:

3-4-1. Objective functions

- Economic objective function
Maximization of total profit is considered as the first objective function which can be formulated as Eq. (1).

$$Max OF_1 = Income_{total} - Cost_{total} + IR_N UB_N \quad (1)$$

The total income of the supply chain can be calculated by Eq. (1-1).

The profit of investing unexpended budget equals $IR_N UB_N$.

- Environmental objective function

Minimization of total unreturned products of customer zones is the second objective function of the proposed model, which can be formulated by Eq. (2).

$$Min OF_2 = \sum_{n \in N} \sum_{t \in T} \sum_{d \in D} \sum_{k \in K} \sum_{p \in P} f_{d,k,p}^{n,t} - \sum_{n \in N} \sum_{t \in T} \sum_{k \in K} \sum_{c \in C} \sum_{p \in P} f_{k,c,p}^{n,t} \quad (2)$$

- Social objective function

Maximization of job creation as a social responsibility is considered as the third objective function of the proposed model, which can be calculated using Eq. (3).

$$Max OF_3 = \sum_{m \in M} J_m OM_m^{NT} + \sum_{d \in D} J_d OD_d^{NT} + \sum_{c \in C} J_c OC_c^{NT} + \sum_{r \in R} J_r OR_r^{NT} \quad (3)$$

3-4-2. Constraints

$$\sum_{s \in S} f_{s,m,p'}^{n,t} = \sum_{p \in P} \rho_{p',p} Q_{m,p}^{n,t} \quad \forall m, p', n > 0, t \quad (4)$$

$$Q_{m,p}^{n,t} = \sum_{d \in D} f_{m,d,p}^{n,t} \quad \forall m, p, n > 0, t \quad (5)$$

$$H_{d,p}^{n,t-1} + \sum_{m \in M} f_{m,d,p}^{n,t} + \sum_{r \in R} f_{r,d,p}^{n,t} = H_{d,p}^{n,t} + \sum_{k \in K} f_{d,k,p}^{n,t} \quad \forall d, p, n > 0, t \neq 1 \quad (6)$$

$$H_{d,p}^{n-1,T} + \sum_{m \in M} f_{m,d,p}^{n,t} + \sum_{r \in R} f_{r,d,p}^{n,t} = H_{d,p}^{n,t} + \sum_{k \in K} f_{d,k,p}^{n,t} \quad \forall d, p, n > 0, t = 1 \quad (7)$$

$$\gamma_p \sum_{c \in C} f_{c,r,p}^{n,t-1} = \sum_{d \in D} f_{r,d,p}^{n,t} \quad \forall r, p, n > 0, t \quad (8)$$

$$\gamma_p \sum_{c \in C} f_{c,r,p}^{n-1,T} = \sum_{d \in D} f_{r,d,p}^{n,t} \quad \forall r, p, n > 0, t = 1 \quad (9)$$

$$(1 - \gamma_p) \sum_{c \in C} f_{c,r,p}^{n,t} = \sum_{c' \in C'} f_{r,c',p}^{n,t} \quad \forall r, p, n > 0, t \quad (10)$$

$$\sum_{l \in L} \varepsilon_{k,p,l}^{n,t} = 1 \quad \forall k, p, n > 0, t \quad (11)$$

$$S_{k,p,l}^{n,t} \leq \varepsilon_{k,p,l}^{n,t} Dem_{k,p,l}^{n,t} \quad \forall k, p, l, n > 0, t \quad (12)$$

$$\sum_{d \in D} f_{d,k,p}^{n,t} + \sum_{l \in L} S_{k,p,l}^{n,t} = \sum_{l \in L} \varepsilon_{k,p,l}^{n,t} Dem_{k,p,l}^{n,t} \quad \forall p, k, n > 0, t \quad (13)$$

$$\sum_{l' \in L'} \varphi_{k,p,l'}^{n,t} = 1 \quad \forall k, p, n > 0, t \quad (14)$$

$$\sum_{l' \in L'} \beta r_{k,p} IP_{k,p,l'}^{n,t} \varphi_{k,p,l'}^{n,t} \leq (1 - \alpha_{k,p}) \sum_{d \in D} f_{d,k,p}^{n,t} \quad \forall k, p, n > 0, t \quad (15)$$

$$\sum_{c \in C} f_{k,c,p}^{n,t} = \alpha_{k,p} \sum_{d \in D} f_{d,k,p}^{n,t} + \sum_{l' \in L'} \beta r_{k,p} IP_{k,p,l'}^{n,t} \varphi_{k,p,l'}^{n,t} \quad \forall k, p, n > 0, t \quad (16)$$

$$\sum_{k \in K} f_{k,c,p}^{n,t} = \sum_{r \in R} f_{c,r,p}^{n,t} \quad \forall c, p, n > 0, t \quad (17)$$

$$OM_m^n \geq OM_m^{n-1} \quad \forall m, n > 0 \quad (18)$$

$$OD_d^n \geq OD_d^{n-1} \quad \forall d, n > 0 \quad (19)$$

$$OC_c^n \geq OC_c^{n-1} \quad \forall c, n > 0 \quad (20)$$

$$OR_r^n \geq OR_r^{n-1} \quad \forall r, n > 0 \quad (21)$$

$$SB_n = \sum_{m \in M} FO_m^{n+1} (OM_m^{n+1} - OM_m^n) + \sum_{d \in D} FO_d^{n+1} (OD_d^{n+1} - OD_d^n) + \sum_{c \in C} FO_c^{n+1} (OC_c^{n+1} - OC_c^n) + \sum_{r \in R} FO_r^{n+1} (OR_r^{n+1} - OR_r^n) + \sum_{m \in M} \sum_{o \in O} FA_{m,o}^{n+1} (O_{m,o}^{n+1}) \quad \forall n < N \quad (22)$$

$$SB_n + UB_n = B_n + IR_{n-1} UB_{n-1} \quad \forall n \in \{1, 2, \dots, n-1\} \quad (23)$$

$$SB_n + UB_n = B_n \quad n = 0 \quad (24)$$

$$UB_n = IR_{n-1}UB_{n-1} \quad \forall n = N \tag{25}$$

$$\sum_{o \in O} O_{m,o}^n \leq OM_m^n \quad \forall m, n > 0 \tag{26}$$

$$\sum_{p \in P} Ur_{m,p} Q_{m,p}^{n,t} \leq U_m \sum_{0 < n' \leq n, n' \in N} \sum_{o \in O} Exp_{m,o}^{n'} \quad \forall m, n > 0, t \tag{27}$$

$$\sum_{0 < n' \leq n, n' \in N} \sum_{o \in O} Exp_{m,o}^{n'} \leq Cap_m^{\max} \quad \forall m, n > 0 \tag{28}$$

$$\sum_{p \in P} Ur_p H_{d,p}^{n,t} + \sum_{m \in M} \sum_{p \in P} Ur_p \frac{f_{m,d,p}^{n,t}}{A_{m,d}} + \sum_{r \in R} \sum_{p \in P} Ur_p \frac{f_{r,d,p}^{n,t}}{A_{r,d}} \leq OD_d^n Cap_d^{\max} \quad \forall d, n > 0, t \tag{29}$$

$$\sum_{k \in K} \sum_{p \in P} Ur_p f_{k,c,p}^{n,t} \leq OC_c^n Cap_c^{\max} \quad \forall c, n > 0, t \tag{30}$$

$$\sum_{c \in C} \sum_{p \in P} Ur_p f_{c,r,p}^{n,t} \leq OR_r^n Cap_r^{\max} \quad \forall r, n > 0, t \tag{31}$$

$$OM_m^n, OD_d^n, OC_c^n, OR_r^n, O_{m,o}^n, \epsilon_{k,p,l}^{n,t}, \phi_{k,p,l'}^{n,t} = \{0,1\} \tag{32}$$

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

Eq. (4) assures that each manufacturer provides sufficient raw materials in each tactical period. Eq. (5) indicates that produced products will be transported to distribution centers. Eq (6) and Eq. (7) indicate the balance of goods for distribution centers and Eq. (8) and Eq. (9) assure the balance of good among distribution centers and recovery centers. Eq. (10) assures the flow of goods among recovery centers and disposal centers. Selecting only one price level in each tactical period is guaranteed by Eq. (11). Based on Eq. (12), shortage in each customer zone should be less than total demand. Eq. (13) indicates that sum of met demand and shortage for each product equals total demand of related customer zone. Eq. (15) is the extra constraint which prevents selecting buying prices which lead to returning used products more than met demand. The balance of goods for each customer zone and collection center is considered by Eq. (16) and Eq. (17). Eqs. (18)-(21) guarantee that the opened facilities cannot be closed through next strategic periods. Eq. (22) considers the assigned budget for each strategic period which can be used to open facilities and increase the capacity of manufacturers. Eqs. (23)-(25) limits sum of expended and unused budget to assigned budget for each period. Eq. (26) indicates that each manufacturer can activate at most one capacity option during each strategic period. This fact that the manufacturers cannot proceed more than their capacity is considered via Eq. (27). Eq. (28) limits the total activated capacity for each manufacturer to maximum allowable installable capacity. The capacity limitations for other

facilities are stated by Eqs. (29)-(31). Finally, the decision variables are considered in Eq. (32).

3-5. Solution approach

In this paper, an e-constraint approach is used in order to make a single-objective model. Also, an imperialist competitive algorithm is presented for large size problems.

3-5-1. Single-objective model

In order to have a single-objective function model, an e-constraint approach is used in this paper. Accordingly, the problem is reformulated as a single-objective function model with respect to objective function with most priority and the other objective functions are considered as constraints [42]. Eq. (33) indicates the reformulation of proposed model.

$$\begin{aligned} \max (OF_1(x), OF_2(x), OF_3(x)) \\ \text{s.t.} \\ \text{Constraints} \end{aligned} \Rightarrow \begin{cases} \max OF_1(x) \\ \text{s.t.} \\ OF_2(x) \geq e_2 \\ OF_3(x) \geq e_3 \\ \text{Constraints} \end{cases} \tag{33}$$

where e_i is the epsilon for i th constraint. Finally, the created single-objective model should be solved for different values of e_i .

In this paper, to improve the performance of solution approach, an augmented e-constraint method is used [42]. Eq. (34) indicates the formulation of proposed model with respect to this method.

$$\max z=f_1(x)+\delta\left(\frac{sl_2}{Range_2}+\frac{sl_3}{Range_3}\right)$$

s.t.

$$f_2(x)+sl_2=e_2 \tag{34}$$

$$f_3(x)-sl_3=e_3$$

$$sl_i \geq 0$$

$$(4)-(32)$$

where $Range_i$ indicate range of variations for each objective function. Based on [42], these ranges can be calculated using payoff table achieved via lexicography method. Sl_i indicates slack or surplus variable for each objective function. Using Eq. (32) in e-constraint method lead to more non-dominated solutions and decision maker can choose among them [42].

3-5-2. Approximated solution approach

To solve large size problem, approximated method such as meta-heuristic approaches can be

used. In this paper, an imperialist competitive (ICA) approach is presented.

3-5-2-1. Imperialist competitive algorithm

The imperialist competitive algorithm is one of the well-known population-based evolutionary algorithms has been introduced by [43]. The steps of ICA are as follows:

- Step 1: Initialization of the empires

The first step is generating N_{pop} initial countries which include N_{imp} countries as imperialists and the other are colonies. The structure of solution representation is indicated in Figure 6 which includes a $1 \times (M + D + C + R)$ vector and the value of each cell is a discrete number between 0 to N . This value indicates the strategic period in which the related facility is opened and the zero value means the facility cannot be opened during the planning horizon. The other decision variables are determined based on this vector.

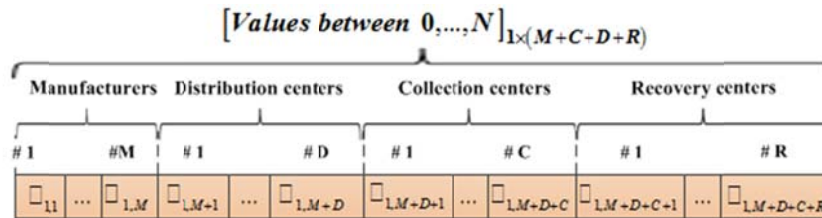


Fig. 6. Solution representation

Then, the number of colonies seized by each imperialist can be calculated with respect to the power of each imperialist. Eq. (35) calculates the power of each imperialist.

$$P_n = \frac{z_n}{\sum_{i=1}^{N_{imp}} z_i} \tag{35}$$

where, z_i is fitness function for i th imperialist which can be calculated using Eq. (34) and P_i is the power of related imperialist. The number of colonies for each imperialist can be calculated using Eq. (36).

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

- Step 2: Movement of colonies toward imperialist

The colonies of each imperialist will move toward their imperialist regarding a deviation. The value of movement and deviation can be calculated using Eq. (37) and Eq. (38), respectively.

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

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

where $U(.)$ is a continuous random variable with Uniform distribution, d is distance among colony and its imperialist, and β and γ are two parameters.

- Step 3: Changing position of colony and imperialist

If a colony reaches a better position rather than its relative imperialist, the position of this colony and imperialist should be exchanged.

- Step 4: Computing total power of empires

The total power of each empire can be calculated using Eq. (39).

$$TP_n = P(imperialist_n) + \zeta mean\{P(colonies)\} \tag{39}$$

where ζ is less than 1 and TP_n is total power of n th empire.

- Step 5: Competition among empires

In this step, the most powerful empire seizes the weakest colony of weakest empire.

- Step 6: Eliminating empires without colony
- If an empire loses all colonies, it should be eliminated from the competition.
- Stop criterion

If only one empire remains in the competition, the algorithm will be stopped, otherwise go to step 2. Figure 7 indicates the flowchart of proposed algorithm.

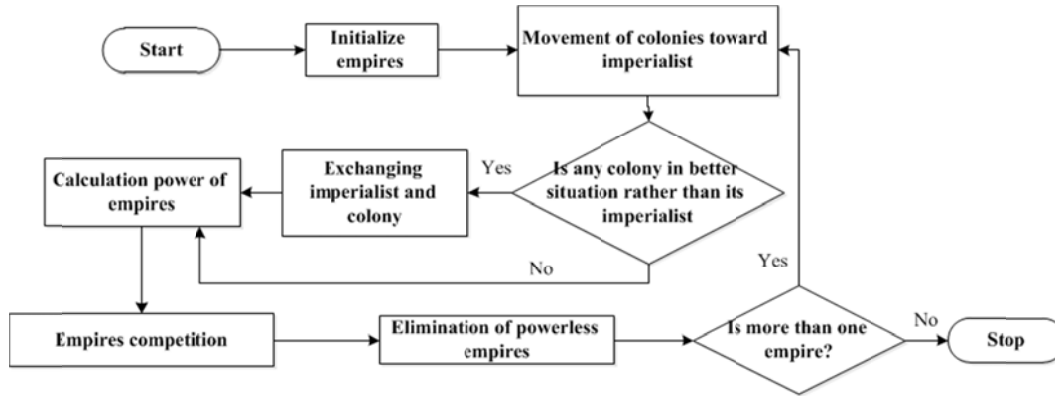


Fig. 7. Flowchart of ICA

4. Numerical Results

In this section, several numerical examples are used to evaluate the proposed model. In this manner, one of these numerical examples is solved exactly using an e-constraint method and sensitivity analysis is considered. The

characteristics of numerical examples are indicated in Table 3. It should be noted that in all numerical examples it is assumed that $L = 5$ and $L' = 5$. The other parameters are generated randomly.

Tab. 3. Characteristic of numerical examples

Problem No.	S	M	D	K	C	R	C'	P'	P	O	N	T
P1	2	2	1	1	1	1	1	2	1	2	2	3
P2	2	3	2	3	2	2	1	4	2	3	2	3
P3	3	4	4	5	4	3	2	5	4	4	3	4
P4	5	5	5	7	5	4	2	10	5	4	3	4
P5	10	7	7	8	5	4	2	12	6	4	4	4
P6	15	10	7	10	6	5	3	15	8	5	5	4
P7	17	12	8	12	8	7	5	15	9	6	5	4
P8	18	15	10	15	10	10	7	20	10	8	5	4
P9	20	20	15	20	12	12	8	25	15	9	5	4
P10	25	25	20	25	15	15	10	30	20	10	5	4

4-1. Exact solving approach

Consider a SCND problem for P3 which its characteristic is indicated in Table 3. First, this problem is formulated using Eqs. (1)-(32). Then, the multi-objective model is transformed to a

single-objective model using Eq. (34). Table 4 indicates maximum and minimum of second and third objective functions regarding lexicography method.

Tab. 4. Variation of second and third objective functions

	Minimum value of objective function	Maximum value of objective function	Range of variation	Number of epsilons	e_1	e_2	e_3
OF2	0	75	0-75	3	0	37	75
OF3	529	604	529-604	3	529	567	604

To solve the proposed, we used GAMS 24.5 software in which CPLEX solver is set. Also,

three different levels are considered for second and third objective functions. Table 5 indicates the results of solving model for different values

of e_i . The optimum value of each objective function regardless the other objective functions can be observed in Table 5, too.

Tab. 5. Non-dominated solutions for numerical example

# Solution	OF1 value	OF2 value	OF3 value
1	3778319.067	0	535
2	1841633.779	0	569
3	3789504.736	37	530
4	1841652.594	37	569
5	3901669.514	75	530
6	1842786.177	75	569
7	-27736.884	0	604
Optimum	3906363.047	0	604

4-1-1. Sensitivity analysis

To evaluate the proposed model more accurately, a sensitivity analysis is considered on some parameters.

- Sensitivity analysis on budget parameter

Figure 8(a) indicates the variation of economic and social objective functions with respect to the variation of the budget. Accordingly, it can be observed that increasing the budget, increases the profit. It should be noted that the growth rate of profit will be decreased gradually because the demand of customer zones are fixed. So, only a portion of budget is required to meet demands and the remained budget can be invested. The convergence of met demand in Figure 8(a) confirms this fact. Also, Figure 8(a) indicates that increasing of the budget leads to increasing job opportunities till the demand is met completely. The percentage of used budget and percent of activated of facilities are indicated in Figure 8(b). It can be observed in Figure 8(b) that the percentage of the used budget will decrease gradually regarding fixed demand. In fact, the extra budget will be invested in other projects. The convergence in the percent of activated facilities assures this fact.

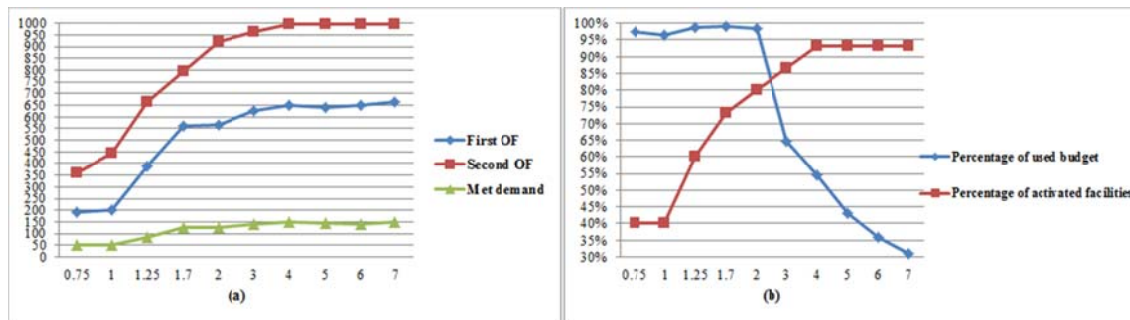


Fig. 8. Sensitivity analysis of budget

- Sensitivity analysis on demand parameter
- The variation of the economic objective function and total met demand with respect to the demand

are indicated in Figure 9, in which both increase via increasing the demand.

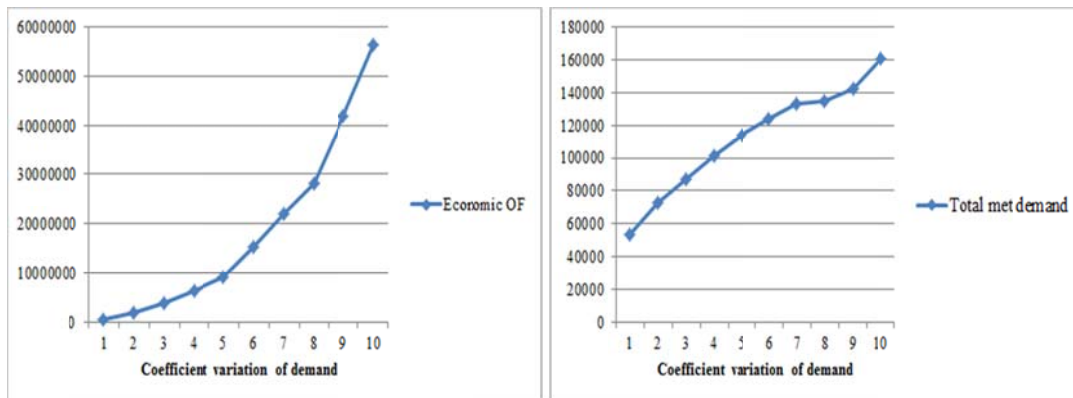


Fig. 9. Sensitivity analysis of demand

- Sensitivity analysis on elasticity coefficient of selling and buying price

Figure 10(a) indicates the effect of changing $\beta_{k,p}$ on profit. Accordingly, it can be concluded that increasing in the elasticity coefficient of selling price leads to a decrease in profit. Based

on Eq. (I), increasing of $\beta_{k,p}$ reduces the possible range for products' pricing and consequently the met demand will be decreased,

as shown in Figure 10(b). In fact, meeting the demands using low price is not effective, economically.

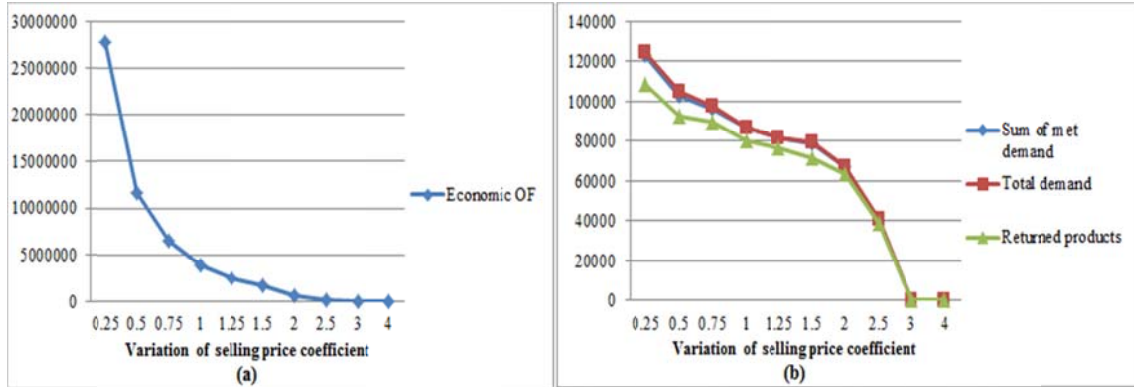


Fig. 10. Sensitivity analysis of selling price coefficient

Figure 11(a) indicates the effect of change in $\beta_{k,p}^r$ on percentage of returned and bought products. Based on Figure 11-a, the influence of the changes in elasticity coefficient of buying price on returned and bought products is not considerable. The variations of the total cost of

returning used products and economic objective function with respect to changing $\beta_{k,p}^r$ are indicated in Figure 11(b) and Figure 11(c), respectively. It can be observed that increasing of $\beta_{k,p}^r$ decreases buying cost of used products and increases profit.

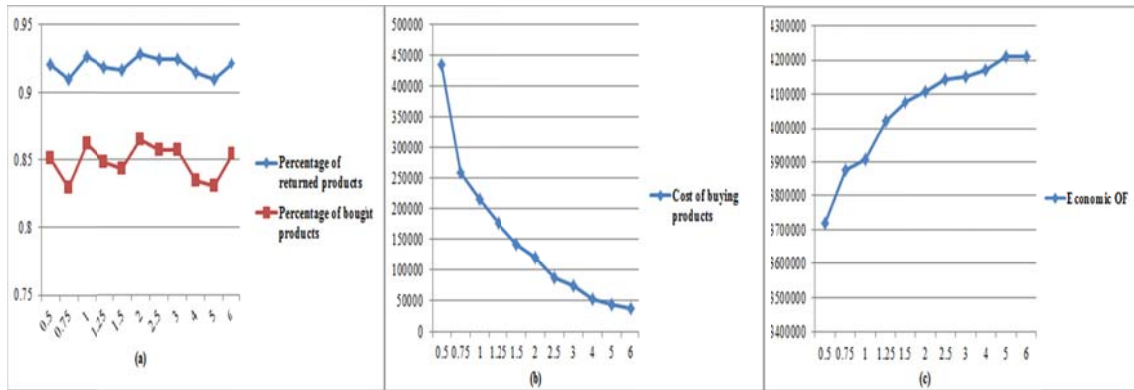


Fig. 11. Sensitivity analysis of buying price coefficient

- Effect of dynamic pricing on profit

In order to compare dynamic pricing approach with static one, several numerical examples which their characteristic is indicated in Table 6, is used. The economic objective function for these numerical examples is calculated for both

to dynamic pricing mechanism and static pricing mechanism. It should be noted that in static pricing approach a constraint which prevents changing prices during planning horizon, is added to the model. The results are indicated in Figure 12.

Tab. 6. Characteristic of numerical examples

Problem No.	S	M	D	K	C	R	C'	P'	P	O	L	L'	N	T
P2	2	3	2	3	2	2	1	4	2	3	5	5	2	3
P3	3	4	4	5	4	3	2	5	4	4	5	5	3	4
P4	5	5	5	7	5	4	2	10	5	4	5	5	3	4
P5	10	7	7	8	5	4	2	12	6	4	5	5	4	4
P6	15	10	7	10	6	5	3	15	8	5	5	5	5	4

Based on Figure 12, it can be observed that the profit in case of dynamic pricing is more than static case. Also, this difference will be increased

with respect to the size of the problems. Hence, it seems that dynamic pricing approach is more economic.

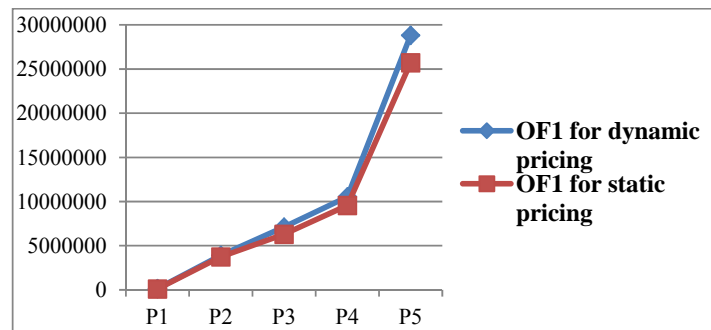


Fig. 12. Profit for dynamic and static pricing approach

2.4. Approximated approach

In this section, numerical examples are solved using ICA. In this manner, the parameters of proposed algorithm are adjusted using Taguchi method [44, 45].

Based on Taguchi method, three different levels are considered for parameters of ICA in this paper [46]. Table 7 indicates these levels. Then, L27 Taguchi design is considered for proposed algorithm using Minitab software. Figure 13 indicates the values of the signal to noise for different levels of parameters. Since bigger value of the signal to noise is desirable, the optimum level of parameters is highlighted in Table 7.

Tab. 7. Level of ICA parameters

Parameter	Level of Parameter		
	Low	Medium	High
Population size	20	30	40
Number of imperialists	5	10	15
Max It	50	100	200
Movement random number	1	2	3
Deviation coefficient	0.5	0.6	0.7
Impact factor of colony	0.05	0.1	0.2

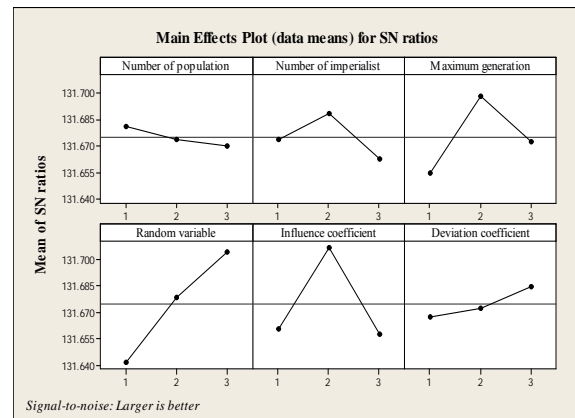


Fig. 13. Taguchi results for ICA

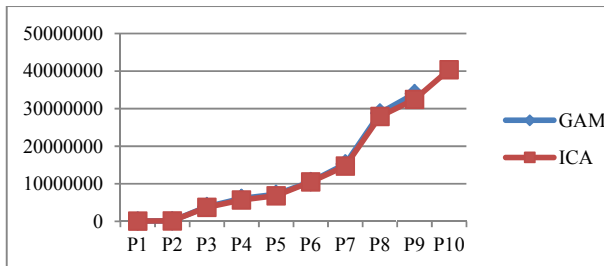
To evaluate the efficiency of ICA, each numerical example is modeled using Eq. (34). Then, the single-objective model is solved using both GAMS and ICA. The results of solving numerical examples using GAMS and ICA are indicated in Table 8.

Tab. 8. Results of solving numerical examples via GAMS and ICA

Problem No.	OF _{e-Constraint}		CPU time for ICA
	GAMS	ICA	
P1	90498	88971	19.45
P2	135182	127267	102.54
P3	3901670	3751260	382.16
P4	6108162	5689447	612.5
P5	7162209	6833786	847.47
P6	10532110	10523105	1907.04
P7	15288412	14699044	3348.44
P8	28825231	27953556	5061.32
P9	33984308	32461417	8734.46
P10	NA	40353294	12284.29

It can be observed that using GAMS in 15000 seconds leads to no solution for P10, while the ICA achieves a solution which indicates the capability of the proposed algorithm. Also, comparing the results for GAMS and ICA indicates that there is no significant difference among the exact and approximated approaches. In fact, the proposed ICA can achieve acceptable near optimum solutions.

Figure 14 indicates the economic objective functions for each numerical example solved by GAMS and ICA.

**Fig. 14. Results of numerical example for ICA and GAMS**

5. Conclusion

In this paper, an integrated multi-objective model for a closed-loop SCND problem was presented. For sake of dynamism, several strategic periods were regarded which made changing the structure of supply chain possible. Also, pricing decisions in both forward and reverse logistics were considered. Finally, an augmented e-constraint method was used to make single-objective model and an imperialist

competitive algorithm was presented to solve large size problems.

Since the sustainable SCND problem is attended widely during last decades, so presenting other objective functions to consider environmental and social concerns is suggested as an extension to this paper. Also, considering uncertainty in the proposed model leads to more realistic and reliable results.

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