Journal of Optimization in Industrial Engineering Vol.12, Issue 1, Winter and Spring 2019, 173 - 194
DOI: 10.22094/joie.2018.476.0

A Multi-Objective Fuzzy Approach to Closed-Loop Supply Chain Network Design with Regard to Dynamic Pricing

Soroush Avakh Darestani [a,*] , Faranak Pourasadollah [b]

[a]*Department of Industrial Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran*
[b]*Department of Industrial Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*
Received 15 April 2015; Revised 09 August 2016; Accepted 19 February 2018

Abstract

During the last decade, reverse logistics networks received a considerable attention due to economic importance and environmental regulations and customer awareness. Integration of leading and reverse logistics networks during logistical network design is one of the most important factors in supply chain. In this research, an Integer Linear Programming model is presented to design a multi-layer reverse-leading, multi-product, and multi-period integrated logistics network by considering multi-capacity level for facilities under uncertainty condition. This model included three objectives: maximizing profit, minimizing delay of goods delivering to customer, and minimizing returned raw material from suppliers. This research gives financial incentives to encourage customers in order to return their used product. Considering that the remaining value of used products is the main incentive of a company to buy second-handed goods, a dynamic pricing approach is determined to define purchase price for these types of products, and based on that, the percentage of returned products were collected by customers. In addition, in this study, parameters have uncertainty features and are vague; therefore, at first, they are converted into exact parameters and, then, because model is multi-objective, the fuzzy mathematical programming approach is used to convert multi-objective model into a single objective; finally, the model by version 8 of Lingo is run. In order to solve a large-sized model, a non-dominated sorting genetic algorithm II (NSGA-II) was applied. Computational results indicate the effect of the proposed purchase price on encourage customers to return the used products.

Keywords: Integrated supply chain network; Fuzzy mathematical programming; Dynamic pricing approach; Integer programming; Quality levels.

1. Introduction

A major portion of the supply chain management (SCM) have been formerly focused on production and distribution operations, i.e., on direct current of the chain composed of the suppliers, manufacturers, distributors, retailers, and the customers (Akçali *et al*., 2009). In recent decades, paying attention to environmental issues, legal requirements and the economic benefits from reclamation and reconstruction activities of the product have made many major companies focus on implementation of the activities like collection, reclamation, reconstruction or recycling of the products, which are at the end of the traditional supply chain (SC), and their own shelf life, and to obtain remarkable successes in this field (Meade *et al*., 2007). Product reclamation reduces the need for the first-hand material, energy consumption, and the space required for disposal of the products. Therefore, from a business point of view, these systems have a significant role in the profitability increase of the organizations (Guide *et al*., 2003). All these issues have resulted in paying attention to the reverse current in the chain and development of the range of SCM activities. Performance optimization of this developed SC requires creation of an efficient and effective infrastructure through the supply chain network design (SCND). This is why the network design for product reclamation has attracted the attentions of several researchers over the last decade (Akçali *et al*., 2009).

The SCND is one of the most important strategic decisions in the SC. Generally, the logistics network design decisions include determination of the number, place, and capacity of the facilities and amount of the currents between them (Amiri, 2006). According to previous studies, design of direct and reverse logistics networks has been done separately, which leads to sub-optimality of the design, yet it should be considered that the reverse logistics network configuration has a great effect on direct logistics network, and vice versa. Design of direct and reverse logistics networks should be performed in an integrated form (Lee and Dong, 2008). On the other hand, one of the key topics for the companies connected with product reclamation is the acquisition method of the used products. In fact, this activity is the first step for product reclamation and starter of other activities of the reclamation system. Some producers have managed to influence the amount of returned products through offering financial incentives to the product owners. In addition, obviously, the amount of the financial incentive offered by the company (the purchase price of the returned goods) influences the quality of the returned products. Therefore, for the companies connected with product reclamation, adaptation of a proactive approach and implementation of an appropriate approach

*Corresponding author Email address: avakh@qiau.ac.ir

in order to gain the returned products through offering an appropriate incentive plays a decisive role (Aras *et al*., 2008).

On the other hand, the dynamic and complicated nature of the SC causes a high degree of uncertainty in SC planning decisions and imposes remarkable effects on the overall performance of the supply chain network (SCN) (Klibi *et al*., 2010).

In many cases, in order to overcome the uncertainty, usually, the contingency approach is applied. However, application of this approach arises two major problems. Firstly, in many real cases, there are no historical data for uncertainty parameters; therefore, we can barely have accurate and real random distributions of uncertainty parameters. Secondly, in most of the works done in reverse SCND under uncertainty, the uncertainty has been modelled through the scenario according to contingency planning where, in such cases, a large number of the scenarios lead to computational challenges in uncertainty presentation (Pishvaee and Torabi, 2010). Thus, in order to overcome this problem, the fuzzy theory can be used which simultaneously provides a framework for managing different types of uncertainty, including the fuzzy numbers, due to lack of knowledge and also flexibility in constraints and objectives (Dubois *et al*., 2003).

In this research, considering the role of pricing in uncertainty reduction of the returned products and also the effect of the product return rate on the number, location, and quantity of the facilities for product reclamation, a mixed integer linear programming (MILP) mathematical model has been presented for integrated design of the multi-level, multi-period, and multi-product reverse-direct SCN considering the price of the returned products. In the direct direction, the mentioned model includes the suppliers, producers, and distributors and, in the reverse direction, it contains the collection/inspection, recycling.

Table 1
Classification of the Logistics Network Design Issues (Ramezani et al., 2013).

Category	Detail	Abbreviation Code
Type of network	Forward logistic	FL
	Reverse logistic	RL
	Forward/Reverse logistic	FRL
Layers of network	Supplier centres	SC
	Production centres	PC
	Distribution centres	DisC
	Collection centres	CIC
	Redistribution centres	RDisC
	Recovery centres	RCC
	Recycling centres	RYC
	Remanufacturing centres	RMC
	Disposal centres	DC
Features of model	Period	
	Multi-period	MPr
	Single-period	SPr
	Product	
	Multi-product	MP
	Single-product	SP
	Parameters	
	Deterministic	D
	Stochastic	S
	Facility capacity	
	Uncapacitated	UC
	Capacitated	CA
Decisions of model	Inventory	I
	Demand satisfaction quantity	DS
	Price of products	PR
	Transportation amount	TA
	Facility capacity	FC
	Location/alocation	L
	Single sourcing	SS
Objective	Cost	C
	Price	P
	Quality	Q
	Responsiveness	R
	Delivery time	DT
	Max robustness	RO
	Environmental	E
	Total Inventory	TI

2. Literature Review

In most of the researches, design of the forward and reverse logistics networks has been considered separately; however, configuration of the reverse logistic network has a strong impact on the forward logistics network, and vice versa. Considering the fact that the separate designing may cause optimality given the expenses, service level, and accountability, thus, design of the forward and reverse logistics networks should get integrated (Pishvaee *et al*.,

2009). The results from integration of forward and reverse SC are the closed-loop supply chain (CLSC) or integrated SC (Hassanzadeh Amin and Zhang, 2013).
This section reviews a majority of the works done in the field of designing direct, reverse and integrated logistics networks. For this purpose, the logistics network design models were studied based on the logistics network levels, characteristics of the issue and outputs of the model according to table1. Most of the existing literature in the field of the logistics network design, including different facility locating models, are based on mixed integer linear programming. These models include different types of simple models, such as facility locating with unlimited capacity, to the more complicated models, such as the multi-category models with limited capacity, or multi-product models (Pishvaee et al., 2010).
To structure the literature review and show difference of this work from others, the review of existing works on the SCND problem are given in Table 2. The abbreviation codes of this table are given in Table1, respectively.
The following table shows the presented models in the field of direct, reverse and integrated logistics offered by the researchers in recent years.

Table 2
Presentation of the researches carried out in field of direct, reverse and integrated logistics

Authors	Type of network	Layer of network	Features of model	Decisions of model	Objectives
Sabri and Beamon	FL	SC,PC,DisC	Ca, D, MP, SPr	L,TA	C,RO
Melachrinoudis et al.	FL	PC,DisC	Ca, D, SP, SPr	L,TA	C,Res
Guillen et al.	FL	PC,DisC	Ca,S,MP,MPr	L,TA	P,Res
Amiri	FL	PC,DisC	Ca, D, SP, SPr	L,FC,TA	C
Altiparmak et al.	FL	SC,PC,DisC	Ca, D, SP, SPr	L,TA	C,Res
Meepetchdee and Shah	FL	PC,DisC	UC,D,SP,SPr	L,TA	C,RO
Tsiakis and Papageorgiou	FL	PC,DisC	Ca, D, MP, SPr	L,FC,TA	C
Selim and Ozkarahan	FL	PC,DisC	Ca,D,SP,MPr	L,FC,TA	C, Res
Franca et al.	FL	SC,PC,Disc	Ca,S,MP,MPr	L,TA	P,Q
Bandyopadhyay et al.	FL	SC,PC,DisC,	MP,SPr,D,	I,FC,TA	C,TI
Baghernejad &Dehghani	FL	PC,DisC	MP, SPr	L,TA	C, DT
Marı´n andPelegrin	RL	PC	UC,D,SP,SPr	L,TA	C
Jayaraman et al.	RL	CIC,RCC,RDicS	Ca,D,MP,SPr	L,TA	C
Krikke et al.	RL	CIC,RCC,RDicS	UC,D,SP,SPr	L,TA,I	C
Jayaraman et al.	RL	CIC,RCC	Ca,D,MP,SPr	L,TA	C
Listes and Dekker	RL	CIC, RYC	Ca, S, MP, SPr	L,TA	C
Min et al.	RL	CIC,RCC	Ca,S,MP,SPr	L,TA	C
Uster et al.	RL	CIC,RCC,PC,DicS	UC,D,MP, SPr	L,TA	C
Aras et al.	RL	CIC	UC,D,MP,SPr	L,TA,PR	C
Pishvaee et al.	RL	PC,DisC,	Ca, D, SP, SPr	L,TA	C
Fleischmann et al.	FRL	CIC,RCC,PC,DisC	UC,D,SP,SPr	L,TA,DS	C
Salema et al.	FRL	CIC,RCC,DC,PC,DisC	D,SP,SPr	L,TA,DS	C
Ko and Evans	FRL	RCC,PC,DisC	Ca,D,MP,MPr	L,TA	C
Salema et al.	FRL	CIC,RCC,DC,PC,DisC	Ca,S,MP,SPr	L,TA,DS	C
Min and Ko	FRL	CIC,RCC,PC,DisC	Ca,D,MP,MPr	L,TA	C
Lee and Dong	FRL	CIC,RCC,PC,DisC	Ca,D,SP,SPr	L,TA	C
El-Sayed et al.	FRL	SC,PC,DisC,CIC,RMC,DC	Ca,D,MP,SPr	L,TA	P
Pishvaee et al.	FRL	CIC,RCC,DisC,PC, DC	Ca,D,SP,SPr	L,TC,FC	C,Res
Wang and Hsu	FRL	SC,PC,DisC,CIC,RYC,RMC	SP,SPr,Ca	L,TA	C
Ramezani et al.	FRL	SC,PC,DisC,CIC,DC RMC	S,SP,MPr,Ca, SS	L,TA,FC	P,Res,Q
Keyvanshokooh et al.	FRL	PC,DisC,CIC,DC,RCC	Ca,D,SP,MPr	L,TA,I, C,PR	C
Safari et al.	FRL	PC, DisC,CIC	SPr, SP,S,Ca	L,TA	C,E
Zohal and Soleimani	FRL	SC,PC, DisC,CIC,DC	SP,SPr,D	L,TA	E,C
Our research	**FRL**	**SC,PC,DisC,CIC,RYC**	**Ca,MP,MPr,SS**	**L,TA,I, FC,PR**	**P,Q,DT**

Considering the carried out review of literature, it can be concluded that most of the works done in this field were in certain environment, and despite the fact that some of the parameters such as the demands and amount of the returned goods always follow a vague form, they have been ignored. The interesting point in review of the conducted works is that the strategy is usually considered in the push form in sending the goods level; consequently, the inventories in places like production and distribution centres are not considered as inventories. Moreover, the amount of the returned products has always been considered as a parameter in reverse and closed-loop logistics works, while the percentage of the returned products can increase through persuading the customers. Yet, considering the mentioned items in this research, we seek to overcome the deficiencies.

3. Problem Definition

The network supposed in this research is a multi-level, multi-product and multi-period forward-reverse integrated logistics network. According to Figure 1, products are produced using provided parts from suppliers and delivered to the customers through distribution centres. The sales price of the products and demands of the customer centres in each period are specific. In the reverse flow, the returned products are collected in collection and inspection centres and after quality inspection are divided

into two groups such as commercial returns and recoverable products.
The returns sales products are repaired in collection centres and, then, transferred to the distribution centres as new products. On the other hand, the recoverable products are sent to the disassembly centres; then, the quality parts are sent to production centres for reuse.
The product flow in the forward channel is in a push-pull strategy. On the one hand, the existing inventory level of the distribution centres should reach the base inventory level in each time period which suggests the push strategy. On the other hand, there are the orders of the customer areas that obtain their required goods from the distribution centres and the orders should be satisfied through the inventories of the distribution centres. However, in the reverse channel, the product current is in the pull strategy form and based on the returns from the customers. In this model, the locations of the customers, suppliers, and disposal centres are fixed, and all of the facilities have capacity limitations.
In this research, instead of processing the facilities of the distribution centres in a direct direction and the collection centres in a reverse direction separately, this integrated network has provided the possibility for combined processes in both distribution and collection centres to be established in the same place making some advantages such as cost saving and pollution reduction, compared with separate distributions. On the other hand, transfers of goods between the facilities are in equal levels, which can be mentioned as a safety stock level in similar levels in order to avoid deficiencies. This means that the commercial returns can be transferred to the distribution centres or distribution-collection combined centres after being repaired in collection centres and to be delivered to the customers.
Environmental protection and the residual value of the used products, which can be obtained through recovery processes, are the mainspring of the companies for collection of the products. However, there is always a doubt in either the goods return by customers or not. Therefore, the present research objectives is to persuade the customers to return the goods and, of course, consider the quality level of the products through offering financial incentives.
Hence, our major contribution in this work is to persuade the customers to return the used products considering the financial incentives. By adaptation of a dynamic pricing strategy, not only the model determines the purchase price considering the quality level of the used products, but also decisions are made about percentage of the returned products based on this price.
Moreover, considering the disability or incompleteness of the data in real world situations, especially in the long-term horizon, most of the parameters in closed-loop SCND issue have vague natures; therefore, in order to deal with them, appropriate contingency distributions are used.
The present research follows three objectives: maximizing the profits, minimizing the delay in transferring the products to the customers, and minimizing the total number of the defective raw material and parts from suppliers aiming to determine the number and location of the production, distribution, collection and disassembly facilities and also the currents between facilities and the price offered to the customers for purchase of the returned products. The structure of the SCND is depicted in Figure 1.

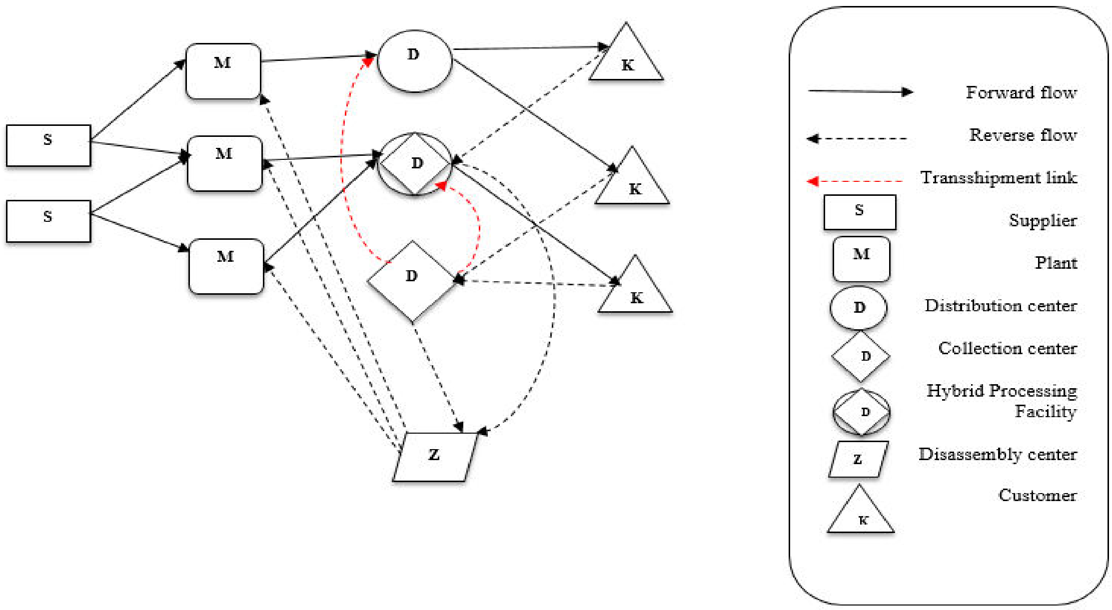

Fig. 1. Research SC Model

In this section, assumptions are presented and the presented models are discussed as follows:

- The model is multi-period and multi-product one.
- Locations of the suppliers and the customers are known and fixed.
- The potential locations of the production, distribution, collection, and disassembly centres are known.
- In addition to the transmission flow between different levels of the chain, there is also the possibility of transmission between the similar levels.
- The number of the facilities, which can be open, and their capacities have limitations.
- In the forward network, all of the customer demands should be satisfied and, in the reverse network, the used products owned by the customers are returned considering the offered purchase price.
- The returned products have different qualities.
- Expenses like the fixed costs and transmission costs are known.

4. Model Formulation

Sets

S	Set of fixed locations of suppliers, (s=1,2,…,S)
M	Set of potential locations of plants, (m=1,2,…M)
D	Set of potential locations available for distribution centres, collection centres, and hybrid processing facilities, (d,d′=1,2,…,D)
K	Set of fixed locations of customers, (k=1,2,…,K)
Z	Set of potential locations of disassembly centres, (z=1,2,..,Z)
P	Set of products, (p=1,2,…,P)
Q	Set of quality levels for used products, (q=1,2,…,Q)
L	Set of price levels for buying used products, (l=1,2,…,L)
I	Set of raw material, (i=1,2,…,I)
T	Set of time periods, (t=1,2,…,T)

Parameters

Demand and potential return:

$\tilde{D}_{kpt}$	Demand of customer k for product p in time period t
$\tilde{R}_{kpqt}$	Potential return of used product p with quality level q from customer k in time period t

Fixed costs:

$F\tilde{C}M_{m}^{h}$	Fixed cost for opening plant m with capacity level h
$F\tilde{C}D_{d}^{h}$	Fixed cost for opening distribution centre d with capacity level h
$F\tilde{C}Y_{d}^{h}$	Fixed cost for opening collection centre d with capacity level h
$S\tilde{C}_{d}^{h}$	Fixed saving cost associated with opening hybrid processing facility d with capacity level h
$F\tilde{C}Z_{z}^{h}$	Fixed cost for opening disassembly centre z with capacity level h

Variable costs:

$P\tilde{C}_{mp}$	Unit production cost of product p at plant m
$\tilde{H}_{dp}$	Inventory carrying cost per unit of product p per period at distribution centre / hybrid processing facility d
$O\tilde{C}_{dp}$	Unit processing cost of product p at distribution centre/ hybrid processing facility d
$C\tilde{C}_{dp}$	Unit collection cost of product p at collection centre /hybrid processing facility d
$C\tilde{P}R_{dp}$	Unit repairing cost of product p at collection centre/ hybrid processing facility d
$C\tilde{R}_{zp}$	Unit disassembly cost of product p at disassembly centre z
$P\tilde{R}_{pt}$	Unit price of product p at customer k in time period t
$S\tilde{P}_{sit}$	Unit purchasing cost of raw material i from supplier s in time period t

Transportation costs:

$T\tilde{C}S_{smit}$	Unit transportation cost for raw material *i* shipped from supplier *s* to plant *m* in time period *t*
$T\tilde{C}M_{mdpt}$	Unit transportation cost for product *p* shipped from plant *m* to distribution centre/ hybrid processing facility *d* in time period *t*
$T\tilde{C}D_{dkpt}$	Unit transportation cost for product *p* shipped from distribution centre/ hybrid processing facility *d* to customer *k* in time period *t*
$T\tilde{C}K_{kdpt}$	Unit transportation cost for returned product *p* shipped from customer *k* to collection centre/ hybrid processing facility in time period t
$T\tilde{C}R_{dd'pt}$	Unit transportation cost for repaired product *p* shipped from collection centre/ hybrid processing

	facility *d* to distribution centre/ hybrid processing facility d´ in time period t
$T\tilde{C}Z_{dzpt}$	Unit transportation cost for recycling product p shipped from collection centre/ hybrid processing facility d to disassembly centre z in time period t
$T\tilde{C}I_{zmit}$	Unit transportation cost for raw material i shipped from disassembly centre z to plant m in time period t
Capacity of facilities	
$C\tilde{A}PS_{si}$	Capacity of supplier s for raw material i
$C\tilde{A}PM_{m}^{h}$	Capacity of plant m with capacity level h
$C\tilde{A}PD_{d}^{h}$	Capacity of distribution centre d with capacity level h
$C\tilde{A}PC_{d}^{h}$	Capacity of collection centre d with capacity level h
$C\tilde{A}PE_{d}^{h}$	Capacity of hybrid processing facility d with capacity level h
$C\tilde{A}PZ_{z}^{h}$	Capacity of disassembly centre z with capacity level h
Number of facilities:	
NX	Maximum number of plants that can be opened
NY	Maximum number of distribution centres that can be opened
NO	Maximum number of collection centres that can be opened
Nμ	Maximum number of hybrid processing centre that can be opened
NZ	Maximum number of disassembly centre that can be opened
Coefficients and ratios:	
$S\tilde{L}_{pq}$	Average redistribution fraction of returned product p with quality level q
$\tilde{\lambda}D_{p}$	Coefficient of using capacity of distribution per unit of product p
$R\tilde{D}_{sit}$	Defect rate of raw material i from suppliers in time period t
$\tilde{a}_{kpqt}$	Minimum expected price of customer k for one unit of returned product p with quality level q in time perod t
$\tilde{b}_{kpqt}$	Maximum expected price of customer k for one unit of returned product p with quality level q in time perid t
$P\tilde{R}C_{kpqt}$	Expected price of customer k for one unit of the returned product p with quality level q in time period t
$R\tilde{C}_{kpqlt}$	Incentives given to customer k per unit of returned product p with quality level q in time period t
Others:	
$T\tilde{D}_{dkpt}$	Delivery time from distribution centre/ hybrid processing centre d to customer k
$T\tilde{E}_{kpt}$	Expected delivery time of customer k per unit of product p in time period t

Decision variables:

Binary variables (related to the establishment of facilities):

X_{d}^{h}	Binary variable equals to 1 if a production centre is opened at location m with quality level h, 0 otherwise
Y_{d}^{h}	Binary variable equals to 1 if a distribution centre is opened at location m with quality level h, 0 otherwise
O_{d}^{h}	Binary variable equals to 1 if a collection centre is opened at location m with quality level h, 0 otherwise
μ_{d}^{h}	Binary variable equals to 1 if a hybrid processing facilities is opened at location m with quality level h, 0 otherwise
Ω_{z}^{h}	Binary variable equals to 1 if a disassembly centre is opened at location m with quality level h, 0 otherwise
Binary variables (relating to the single sourcing of serving customers):	
ADK_{dk}	Binary variable equals to 1 if in the forward network, shipment link is created between distribution centre or hybrid processing facility j and customer k, 0 otherwise
BDK_{dk}	Binary variable equals to 1 if in the reverse network, shipment link is created between customer k and collection centre or hybrid processing facility j, 0 otherwise
Binary variable (relating to selecting one level of price for used products):	
σ_{kpqlt}	Binary variable equals to 1 if the level price l is allocated to the used product p with quality level q returned by customer k in time period t, 0 otherwise (keyvanshokooh *et al.,* 2013)

Continuous variables (relating to the flows of network):

QSM_{smit}	Quantity of raw material i shipped from supplier s to plant m in time period t
QMD_{mdpt}	Quantity of products p shipped from plant m to distribution centre/ hybrid processing facility in time period t
QDK_{dkpt}	Quantity of products p shipped from distribution centre/ hybrid processing facility d to customer k in time period t
QKD_{kdqpt}	Quantity of returned products p with quality level q shipped from customer k to collection centre / hybrid processing facility d in time period t
$QDD_{dd'pt}$	Quantity of repaired products p shipped from collection centre/ hybrid processing facilities d to distribution centre/ hybrid processing facility d´ in time period t
QDZ_{dzpt}	Quantity of returned products p shipped from collection centre/ hybrid processing facility d to disassembly centre z in time period t
QZM_{zmit}	Quantity of raw material i shipped from disassembly centre z to plant m in time period t
	other continuous variables:
INV_{dp}	Inventory level of product p at distribution centre or hybrid processing facility d at the end of time period t
βS_{dp}	Base-stock level of product p of distribution centre or hybrid processing facility d at the beginning of each period
RE_{kpqt}	Percentage of used product p with quality level q collected from customer k in time period t
PRR_{kpqt}	Acquisition price of used product p with quality level q collected from customer k in time period t

According to the above-mentioned notations, the problem can be formulated as follows:

4.1. Objective function

The objectives of the presented model are: (1) maximizing the total profit, (2) minimizing the delay in transferring the products to the customers, and (3) minimizing the total number of the defective raw material pieces obtained from the suppliers.

$$
\begin{aligned}
MAXW_1 = & \sum_d\sum_k\sum_p\sum_t QDK_{dkpt}\tilde{PR}_{pt} - \sum_s\sum_m\sum_i\sum_t QSM_{smit}(\tilde{SP}_{sit} + \tilde{TCS}_{smit}) \\
& - \sum_m\sum_h \tilde{FCM}_m^h X_m^h - \sum_d\sum_h \tilde{FCD}_d^h \times Y_d^h - \sum_d\sum_h \tilde{FCY}_d^h \times O_d^h - \sum_z\sum_h \tilde{FCZ}_z^h \times \Omega_z^h - \sum_d\sum_h \tilde{SC}_d^h \times \mu_d^h \\
& - \sum_m\sum_d\sum_p\sum_t (\tilde{PC}_{mp} + \tilde{TCM}_{mdpt})QMD_{mdpt} - \sum_d\sum_k\sum_p\sum_t (\tilde{OC}_{dp} + \tilde{TCD}_{dkpt})QDK_{dkpt} \\
& - \sum_k\sum_d\sum_p\sum_q\sum_t (\tilde{CC}_{dp} + \tilde{TCK}_{kdpt})QKD_{kdpqt} - \sum_d\sum_p\sum_t \tilde{H}_{dp} \times INV_{dpt} \\
& - \sum_d\sum_{d'}\sum_p\sum_t (\tilde{CPR}_{dp} + \tilde{TCR}_{dd'pt})QDD_{dd'pt} \\
& - \sum_d\sum_z\sum_p\sum_t (\tilde{CR}_{zp} + \tilde{TCZ}_{dzpt})QZ_{dzpt} - \sum_z\sum_m\sum_i\sum_t \tilde{TCI}_{zmit} \times QZM_{zmit} \\
& + \sum_k\sum_p\sum_q\sum_l\sum_t \tilde{RC}_{kpqt} \times \tilde{R}_{kpqt} \times \delta_{kpqt}\left(\frac{l-1}{L-1}\right) - \sum_k\sum_p\sum_q\sum_l\sum_t \tilde{a}_{kpqt}\left(\frac{l-1}{L-1}\right) \times \tilde{R}_{kpqlt} \times \delta_{kpqlt} \\
& - \sum_l\sum_k\sum_p\sum_q\sum_t (\tilde{b}_{kpqt} - \tilde{a}_{kpqt})\left(\frac{l-1}{L-1}\right)^2 \times \tilde{R}_{kpqlt} \times \delta_{kpqlt}
\end{aligned} \tag{1}
$$

$$
MINw_2 = \sum_d\sum_k\sum_p\sum_t (\tilde{TD}_{dkpt} - \tilde{TE}_{kpt})QDK_{dkpt} \tag{2}
$$

$$
MINw_3 = \sum_s\sum_m\sum_i\sum_t QSM_{smit} \times \tilde{RD}_{sit\,i} \tag{3}
$$

4.2. Constraints

The constraints of the proposed mathematical model are explained in detail in the following subsections.

4.2.1. Allocation constraints

$$QDK_{dkpt} = \tilde{D}_{kpt} \times ADK_{dk}, \forall t, k, d, p \quad (4)$$

$$\sum_{d} ADK_{dk} = 1, \forall k \quad (5)$$

$$\sum_{d} QKD_{kdpqt} = RE_{kpqt} \times \tilde{R}_{kpqt}, \forall k, p, q, t \quad (6)$$

$$QKD_{kdpqt} \leq N \times BDK_{dk}, \forall k, d, q, p, t \quad (7)$$

$$\sum_{d} BDK_{dk} = 1, \forall k \quad (8)$$

4.2.2. Balance constraints

$$\sum_{d} QDD_{dd'pt} = \sum_{k} \sum_{q} (s\tilde{l}_{pq}) QKD_{kdpqt}, \forall d, p, t, \quad (9)$$

$$\sum_{d} QDD_{dd'pt} = \sum_{k} \sum_{q} (s\tilde{l}_{pq}) QKD_{kdpqt}, \forall d, p, t, \quad (10)$$

$$\sum_{s} QSM_{smit} + \sum_{z} QZM_{zmit} = \sum_{d} QMD_{mdpt}, \forall m, i, t \quad (11)$$

$$\sum_{d} QDZ_{dzpt} = \sum_{i} QZM_{zmit}, \forall z, p, m, t \quad (12)$$

4.2.3. Inventory constraints

$$\sum_{t' \leq t} \sum_{m} QMD_{mdpt} + \sum_{t' \leq t} \sum_{d'} QDD_{dd'pt} - \sum_{t < t'} \sum_{k} QDK_{dkpt} = \beta S_{dpt}, \forall d, p, t, \quad (13)$$

$$\sum_{t' \leq t} \sum_{m} QMD_{mdpt} + \sum_{t' \leq t} \sum_{j'} QDD'_{dd'pt} - \sum_{t' \leq t} \sum_{k} QDK_{dkpt} = INV_{dpt}, \forall d, p, t \quad (14)$$

4.2.4. Capacity constraints

$$\sum_{m} QSM_{smit} \leq C\tilde{A}PS_{si}, \forall s, i, t \quad (15)$$

$$\sum_{d} \sum_{p} QMD_{mdpt} \leq \sum_{h} C\tilde{A}PM_{m}^{h} \times X_{m}^{h}, \forall m, t \quad (16)$$

$$\sum_{k} \sum_{p} QDK_{dkpt} + INV_{dpt} \leq \sum_{h} C\tilde{A}PD_{d}^{h} \times Y_{d}^{h} + \sum_{h} C\tilde{A}PE_{d}^{h} \times \mu_{d}^{h}, \forall d, t \quad (17)$$

$$\sum_{k} \sum_{q} QKD_{kdpqt} \leq \sum_{h} C\tilde{A}PC_{d}^{h} \times O_{d}^{h} + \sum_{h} C\tilde{A}PE_{d}^{h} \times \mu_{d}^{h}, \forall d, p, t \quad (18)$$

$$\sum_{d} \sum_{p} QDZ_{dzpt} \leq \sum_{h} C\tilde{A}PZ_{z}^{h} \times \Omega_{z}^{h}, \forall z, t \quad (19)$$

4.2.5. Capacity level constraints:

$$\sum_{h} X_{m}^{h} \leq 1, \forall m \quad (20)$$

$$\sum_{h} Y_{d}^{h} \leq 1, \forall d \quad (21)$$

$$\sum_{h} \mu_{d}^{h} \leq 1, \forall d \quad (22)$$

$$\sum_{h} O_{d}^{h} \leq 1, \forall d, \quad (23)$$

$$\sum_{h} \Omega_{z}^{h} \leq 1, \forall z \quad (24)$$

$$Y_d^h + O_d^h + \mu_d^h \le 1, \forall d, h \quad (25)$$

4.2.6. Maximum number of facilities constraints and others:

$$\sum_m \sum_h X_m^h \le NX \quad (26)$$

$$\sum_d \sum_h Y_d^h \le NY, \quad (27)$$

$$\sum_d \sum_h O_d^h \le NO \quad (28)$$

$$\sum_d \sum_h \mu_d^h \le N\mu, \quad (29)$$

$$\sum_z \sum_h \Omega_z^h \le NZ \quad (30)$$

4.2.7. Pricing constraints and others

$$PRR_{kpqt} = a_{kpqt} + \sum(\tilde{b}_{kpqt} - \tilde{a}_{kpqt})\delta_{kpqlt}(\frac{l-1}{L-1}) - \tilde{a}_{kpqt} \times \delta_{kpq1t}, \forall k, p, q, t \quad (31)$$

$$\sum_l \delta_{kpqlt} = 1, \forall k, p, q, t \quad (32)$$

$$RE_{kpqt} = \sum_l (\frac{l-1}{l-1}) \times \delta_{kpqlt}, \forall k, p, q, t. \quad (33)$$

$$PRR_{kpqt} - (1 - BDK_{dk}) \times N \le PR_{k'pqt} + (1 - BDK_{dk'}) \times N, \forall k, k', d, p, q, t \quad (34)$$

$$PRR_{k'pqt} - (1 - BDK_{dk'}) \times N \le PR_{kpqt} + (1 - BDK_{dk}) \times N, \forall k, k', d, p, q, t \quad (35)$$

$$X_m^h, Y_d^h, O_d^h, \mu_d^h, \Omega_z^h, U_f^h, ADK_{dkpt}, BDK_{dkpt}, \delta_{dkpt} \in \{0,1\}, \forall m, d, h, p, t, k, z, f \quad (36)$$

$$QSM_{smit}, QMD_{mdpt}, QDK_{dkpt}, QKD_{kdpt}, QDZ_{dzpt}, QZM_{zmit}, RE_{kpqt}, QDD_{dd'pt}, \\ PRR_{kpqt}, INV_{dp}, \beta S_{dp} \ge 0, \forall s, m, i, i', p, t, d, k, z, f \quad (37)$$

Equation (1) shows the objective function of the model, which maximizes the profit including the total revenues minus the total costs. The revenues include the profit from the product sale, the interests from collection, and recycling and the costs which include the expenses of purchasing the original parts from the suppliers, the fixed costs of providing facilities, product processing expenses in each of the facilities like production, distribution, collection and recycling, transportation costs and also purchasing the used products owned by the customer. As specified in objective function (2), herein, we seek to minimize the interval between delivery of goods to the customers and the time expected by them for receiving the goods. In equation (3), the objective is minimizing the defective primary components from the suppliers. Limitation (4) implies that the existing current should satisfy the customer demands of each area through the production centre or the combined processing facilities in each period of time and for any types of products. According to limitation (5), every customer area has been allocated to only one distribution centre or combined process facilitation centre; in other words, single sourcing shows the services to the customers regions in the direct way. Limitation (6) shows the amount of the returns in each period for each product and with any type of quality. Limitation (7) shows that each customer area can be allocated to only one collection centre or combined process facilitation centre. Limitation (8) shows that if there is no communication flow in the return network from the customer to the collection centre or the combined process facilitation centre, this customer area has not been allocated to that collection centre or the combined process facilitation centre. Limitations (9) to (12) show the balance among the units. Limitation (13) implies the push strategy and certifies that the amount of P product presented to all customer areas until the t-1 period, from total input current to a distribution centre until t period of time should equal the base level of the related inventory (the first inventory of the period). Limitation (14) shows the inventory level of each product type at the end of each period of time for each distribution centre. Cost of the inventory transportation is calculated at the end of each period according to the inventory level. It is worth mentioning that, inventory levels of distribution centres in such a method, in which we have no deficiencies, have been calculated. Limitation (15) guarantees that the total output current from each supplier to all of the workshops should not exceed the capacity of the supplier. Limitation (16) certifies that the total output current from each production centre to the distribution centres should not exceed the capacity of production centres. Limitation (17) guarantees that the total output current from each distribution centre or the combined facilitation centre to the whole customer areas should not exceed the capacity of those facilities. Limitation (18) shows that the total output from each collection centre or the combined processing centres to the redistribution centres or the combined process facilitation centres and disassembly centres should not exceed their capacity. Limitation (19) certifies that the total input current to the disassembly centre should not exceed its capacity. Limitations (20) to (24) certify that each production, distribution, combined process facilitation and disassembly centres can have ultimately one capacity level, and limitation (25) guarantees that eventually one facilitation type opens in a potential place. Limitations (26) to (30), respectively, limit the number of production, distribution, collection, combined and recycling centres which can be open. Limitation (31) calculates the purchase price of each type of used products with a specified quality level for each customer area, which can be different in each period of time. Limitation (32) shows that, in each period of time, only one price level should be selected for each customer area that returns the used product with q quality level. Limitation (33) shows the percentage of each type of the used product with a specific quality level in each period of time for each customer area. Limitations (34) and (35) certify that if two different customer levels are allocated to a collection or combined process facilitation centre, in order to sell the used products, the returned products of these areas must be purchased with equal prices. Equations (36) and (37) show the limitations related to the type of problem variables.

4.3. Proposed methodology

Since the model deals with imprecise parameters in MOILP problems, we use the contingency planning approach for managing the uncertainties. In order to solve the MOILP problem considering the uncertainty in the parameters, a two-step approach has been presented in which, in the first phase, a new method is used in order to convert the fuzzy parameters into certain parameters; in the next phase, the approach by (Torabi and Hassani, 2008) has been applied in order to convert the multi-objective goal into a mono-objective one; consequently, the model was solved using Lingo software version8 in small sizes.

In literature, there are several new methods for dealing with the contingency models with vague coefficients in the functions and the limitations. In this research, it is attempted to use the efficient contingency method presented by Jimenez et al. (2007) by comparing the mentioned methods, because this method benefits from advantages that differentiate it from other methods:

- This method is efficient for solving fuzzy linear problems, because, in addition to maintaining the linearity, the number of limitations and the objective functions do not increase.
- The presented method (Jimenez et al., 2007) is based on strong mathematical concepts such as the expected interval and the expected value from the fuzzy numbers.
- This method can support different types of triangular, trapezoidal and nonlinear membership functions in both two symmetrical and asymmetrical types.

As stated earlier, the mentioned method is defined based on the "expected interval" and "expected value" from the fuzzy numbers.

Assuming that $\tilde{C}$ is a triangular fuzzy number, the following equation can be defined as a $\tilde{C}$ membership function:

$$\mu_{\tilde{c}}(x) = \begin{cases} f_c(x) = \dfrac{x - c^p}{c^m - c^p} & if\ c^p \le x \le c^m \\ 1 & if\ x = c^m \\ g_c(x) = \dfrac{c^o - x}{c^o - c^m} & if\ c^m \le x \le c^o \\ 0 & if\ x \ge c^o \end{cases} \tag{38}$$

in which c^m, c^p, c^o are three prominent points (probably the most pessimistic and the most optimistic values). According to Jimenez's method, the expected interval (EI) and the expected value (EV) from the triangular fuzzy number can be defined as follows:

$$EI(\tilde{C}) = [E_1^C, E_2^C] = [\int_O^1 f_c^{-1}(x)dx, \int_O^1 g_c^{-1}(x)dx] = [\frac{1}{2}(c^p + c^m), \frac{1}{2}(c^m + c^o)] \tag{39}$$

$$EV(\tilde{C}) = \frac{E_1^C + E_2^C}{2} = \frac{C^P + 2C^m + C^o}{4} \tag{40}$$

According to the ranking method of Jimenez (1996), each pair of ã and b̃ fuzzy numbers can be defined in which degree of ã is greater than b̃:

$$\mu_M(\tilde{a},\tilde{b}) = \begin{cases} 0 & \text{if } E_2^a - E_1^b < 0 \\ \dfrac{E_2^a - E_1^b}{E_2^a - E_1^b - (E_1^a - E_2^b)} & \text{if } 0 \in [E_1^a - E_2^b, E_2^a - E_1^b] \\ 1 & \text{if } E_1^a - E_2^b > 0 \end{cases} \tag{41}$$

According to equation (41), $\tilde{a}_i x \geq \tilde{b}$ equals the following equation:

$$\frac{E_2^{a_i x} - E_1^{b_i}}{E_2^{a_i x} - E_1^{a_i x} + E_2^{b_i} - E_1^{b_i}} \geq \alpha, i = 1,..., l \tag{42}$$

The above-mentioned equation can be rewritten as follows:

$$[(1-\alpha)E_2^{a_i} + \alpha E_1^{a_i}]x \geq \alpha E_2^{b_i} + (1-\alpha)E_1^{b_i}, i = 1,...., l \tag{43}$$

Therefore, considering the above explanations, we can transform the fuzzy model into certain model as follows:

4.3.1. Equivalent certain model

Considering the model presented by Jimenez et al, the crisp model for the main equation will be as follows:

$$\begin{aligned} MAXw_1 = &\sum_d\sum_k\sum_p\sum_t\left(\frac{PR_{pt}^p + 2PR_{pt}^m + PR_{pt}^o}{4}\right)QDK - \sum_m\sum_h\left(\frac{FCM_{mh}^p + 2FCM_{mh}^m + FCM_{mh}^o}{4}\right)X_{mh} \\ &- \sum_S\sum_m\sum_i\sum_t\left(\frac{SC_{si}^p + 2SC_{si}^m + SC_{si}^o + TCS_{smit}^p + 2TCS_{smit}^m + TCS_{smit}^o}{4}\right)QISM_{smit} \\ &- \sum_d\sum_h\left(\frac{FCD_{dh}^p + 2FCD_{dh}^m + FCD_{dh}^o}{4}\right)Y_{dh} - \sum_d\sum_h\left(\frac{FCY_{dh}^p + 2FCY_{dh}^m + FCY_{dh}^o}{4}\right)O_{dh} \\ &- \sum_z\sum_h\left(\frac{FCZ_{zh}^p + 2FCZ_{zh}^m + FCZ_{zh}^o}{4}\right)\Omega_{zh} + \sum_d\sum_h\left(\frac{SC_{dh}^p + 2SC_{dh}^m + SC_{dh}^o}{4}\right)\mu_{dh} \\ &- \sum_d\sum_p\sum_t\left(\frac{H_{dp}^p + 2H_{dp}^m + H_{dp}^o}{4}\right)INV_{dpt} - \sum_z\sum_m\sum_i\sum_t\left(\frac{TCI_{zmit}^p + 2TCI_{zmit}^m + TCI_{zmit}^o}{4}\right)QZM_{zmit} \\ &- \sum_m\sum_d\sum_p\sum_t\left(\frac{PC_{mp}^p + 2PC_{mp}^m + PC_{mp}^o + TCM_{mdpt}^p + 2TCM_{mdpt}^m + TCM_{mdpt}^o}{4}\right)QMD_{mdpt} \\ &- \sum_d\sum_k\sum_p\sum_t\left(\frac{OC_{dp}^p + 2OC_{dp}^m + OC_{dp}^o + TCD_{dkpt}^p + 2TCD_{dkpt}^m + TCD_{dkpt}^o}{4}\right)QDK_{dkpt} \\ &- \sum_k\sum_d\sum_p\sum_q\sum_t\left(\frac{CC_{dp}^p + 2CC_{dp}^m + CC_{dp}^o + TCK_{kdpt}^p + TCK_{kdpt}^m + TCK_{kdpt}^o}{4}\right)QKD_{kdpqt} \\ &- \sum_d\sum_{d'}\sum_p\sum_t\left(\frac{CPR_{dp}^p + CPR_{dp}^m + CPR_{dp}^o + TCR_{dd'pt}^p + 2TCR_{dd'pt}^m + TCR_{dd'pt}^o}{4}\right)QDD_{dd'pt} \end{aligned}$$

$$-\sum_{d}\sum_{z}\sum_{p}\sum_{t}(\frac{CR_{zp}^{p}+2CR_{zp}^{m}+CR_{zp}^{o}+TCZ_{dzpt}^{p}+2TCZ_{dzpt}^{m}+TCZ_{dzpt}^{o}}{4})QDZ_{dzpt}$$
$$+\sum_{k}\sum_{p}\sum_{q}\sum_{l}\sum_{t}(\frac{RC_{kpqt}^{p}+2RC_{kpqt}^{m}+RC_{kpqt}^{o}}{4})(\frac{l-1}{L-1})(\frac{R_{kpqt}^{p}+2R_{kpqt}^{m}+R_{kpqt}^{o}}{4})\times\delta_{kpqt}$$
$$-\sum_{k}\sum_{p}\sum_{q}\sum_{l}\sum_{t}(\frac{a_{kpqt}^{p}+2a_{kpqt}^{m}+a_{kpqt}^{o}}{4})(\frac{l-1}{L-1})(\frac{R_{kpqt}^{p}+2R_{kpqt}^{m}+R_{kpqt}^{o}}{4})\times\delta_{kpqt} \quad (44)$$
$$-\sum_{l}\sum_{k}\sum_{p}\sum_{q}\sum_{t}(\frac{b_{kpqt}^{p}+2b_{kpqt}^{m}+b_{kpqt}^{o}-a_{kpqt}^{p}-2a_{kpqt}^{m}-a_{kpqt}^{o}}{4})(\frac{l-1}{L-1})^{2}$$
$$\times(\frac{R_{kpqt}^{p}+2R_{kpqt}^{m}+R_{kpqt}^{o}}{4})\times\delta_{kpqlt}$$

$$MINw_{2}=\sum_{d}\sum_{k}\sum_{p}\sum_{t}(\frac{TD_{dkpt}+2TD_{dkpt}+TD_{dkpt}-TE_{kpt}-2TE_{kpt}-TE_{kpt}}{4})QDK_{dkpt} \quad (45)$$

$$MINw_{3}=\sum_{i}\sum_{s}\sum_{m}\sum_{t}QSM_{smit}(\frac{RD_{sit}^{p}+2RD_{sit}^{m}+RD_{sit}^{o}}{4}) \quad (46)$$

$$QDK \geq [(\frac{\alpha}{2})(\frac{D_{kpt}^{o}+D_{kpt}^{m}}{2})+(1-\frac{\alpha}{2})(\frac{D_{kpt}^{p}+D_{kpt}^{m}}{2})]ADK_{dk},\forall d,k,p,t \quad (47)$$

$$QDK \geq [(\frac{\alpha}{2})(\frac{D_{kpt}^{o}+D_{kpt}^{m}}{2})+(1-\frac{\alpha}{2})(\frac{D_{kpt}^{p}+D_{kpt}^{m}}{2})]ADK_{dk},\forall d,k,p,t \quad (48)$$

$$\sum_{d}ADK_{dk}=1,\forall k \quad (49)$$

$$\sum_{d}QKD_{kdpqt}\leq[(1-\frac{\alpha}{2})(\frac{R_{kpqt}^{m}+R_{kpqt}^{o}}{2})+(\frac{\alpha}{2})(\frac{R_{kpqt}^{m}+R_{kpqt}^{p}}{2})]RE_{kpqt},\forall k,p,q,t \quad (50)$$

$$\sum_{d}QKD_{kdpqt}\geq[(\frac{\alpha}{2})(\frac{R_{kpqt}^{m}+R_{kpqt}^{o}}{2})+(1-\frac{\alpha}{2})(\frac{R_{kpqt}^{m}+R_{kpqt}^{p}}{2})]RE_{kpqt},\forall k,p,q,t \quad (51)$$

$$QKD_{kdpqt}\leq N\times BDK_{dk},\forall k,d,q,p,t \quad (52)$$

$$\sum_{d}BDK_{dk}=1,\forall k \quad (53)$$

$$\sum_{d'}QDD_{dd'pt}\geq\sum_{k}\sum_{q}[(\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2})]QKD_{kdpqt},\forall d,p,t \quad (54)$$

$$\sum_{d'}QDD_{dd'pt}\leq\sum_{k}\sum_{q}[(1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2})]QKD_{kdpqt},\forall d,p,t \quad (55)$$

$$QKD_{kdpqt}\leq N\times BDK_{dk},\forall k,d,q,p,t \quad (56)$$

$$\sum_{d}BDK_{dk}=1,\forall k \quad (57)$$

$$\sum_{d'}QDD_{dd'pt}\geq\sum_{k}\sum_{q}[(\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2})]QKD_{kdpqt},\forall d,p,t \quad (58)$$

$$\sum_{z}QDZ_{dzpt}\leq\sum_{k}\sum_{q}[1-((1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2}))]QKD_{kdpqt},\forall d,p,t \quad (59)$$

$$\sum_{z} QDZ_{dzpt} \geq \sum_{k}\sum_{q}[1-((\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2}))]QKD_{kdpqt}, \forall d,p,t \tag{60}$$

$$\sum_{z} QDZ_{dzpt} \geq \sum_{k}\sum_{q}[1-((\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{o}}{2})+(1-\frac{\alpha}{2})(\frac{sl_{pq}^{m}+sl_{pq}^{p}}{2}))]QKD_{kdpqt}, \forall d,p,t \tag{61}$$

$$\sum_{s} QSM_{smit} + \sum_{z} QZM_{zmit} = \sum_{d} QMD_{mdpt}, \forall m,i,t \tag{62}$$

$$\sum_{d} QDZ_{dzpt} = \sum_{i} QZM_{zmit}, \forall z,p,m,t \tag{63}$$

$$\sum_{t'\leq t}\sum_{m} QMD_{mdpt} + \sum_{t'\leq t}\sum_{d'} QDD_{dd'pt} - \sum_{t<t'}\sum_{k} QDK_{dkpt} = \beta S_{dpt}, \forall d,p,t, \tag{64}$$

$$\sum_{t'\leq t}\sum_{m} QMD_{mdpt} + \sum_{t'\leq t}\sum_{d'} QDD_{dd'pt} - \sum_{t'\leq t}\sum_{k} QDK_{dkpt} = INV_{dpt}, \forall d,p,t \tag{65}$$

$$\sum_{m} QSM_{smit} \leq [\alpha(\frac{CAP_{si}^{p}+CAP_{si}^{m}}{2})+(1-\alpha)(\frac{CAP_{si}^{o}+CAP_{si}^{m}}{2})], \forall s,i,t \tag{66}$$

$$\sum_{d}\sum_{p} QMD_{mdpt} \leq \sum_{h}[\alpha(\frac{CAPM_{mh}^{p}+CAPM_{mh}^{m}}{2})+(1-\alpha)(\frac{CAPM_{mh}^{o}+CAPM_{mh}^{m}}{2})]X_{m}^{h}, \forall m,t, \tag{67}$$

$$\begin{aligned}\sum_{k} QDK_{dkpt} + INV_{dpt} \leq \sum_{h}[\alpha(\frac{CAPD_{dh}^{p}+CAPD_{dh}^{m}}{2})+(1-\alpha)(\frac{CAPD_{dh}^{m}+CAPD_{dh}^{o}}{2})]Y_{d}^{h} + \\ \sum_{h}[\alpha(\frac{CAPE_{dh}^{p}+CAPE_{dh}^{m}}{2})+(1-\alpha)(\frac{CAPE_{dh}^{m}+CAPE_{dh}^{o}}{2})]\times \mu_{d}^{h} \forall d,p,t\end{aligned} \tag{68}$$

$$\begin{aligned}\sum_{k}\sum_{q} QKD_{kdpqt} \leq \sum_{h}[\alpha(\frac{CAPC_{dh}^{m}+CAPC_{dh}^{p}}{2})+(1-\alpha)(\frac{CAPC_{dh}^{m}+CAPC_{dh}^{o}}{2})]\times O_{d}^{h} \\ +\sum_{h}[\alpha(\frac{CAPE_{dh}^{m}+CAPE_{dh}^{p}}{2})+(1-\alpha)(\frac{CAPE_{dh}^{o}+CAPE_{dh}^{m}}{2})]\times \mu_{d}^{h}, \forall d,p,t\end{aligned} \tag{69}$$

$$\sum_{d}\sum_{p} QDZ_{dzpt} \leq \sum_{h}[\alpha(\frac{CAPZ_{zh}^{m}+CAPZ_{zh}^{p}}{2})+(1-\alpha)(\frac{CAPZ_{zh}^{m}+CAPZ_{zh}^{o}}{2})]\Omega_{z}^{h}, \forall z,t \tag{70}$$

$$\sum_{h} X_{m}^{h} \leq 1, \forall m, \tag{71}$$

$$\sum_{h} Y_{d}^{h} \leq 1, \forall d, \tag{72}$$

$$\sum_{h} \mu_{d}^{h} \leq 1, \forall d \tag{73}$$

$$\sum_{h} O_{d}^{h} \leq 1, \forall d \tag{74}$$

$$\sum_{h} \Omega_{z}^{h} \leq 1, \forall z \tag{75}$$

$$Y_{d}^{h} + O_{d}^{h} + \mu_{d}^{h} \leq 1, \forall d,h \tag{76}$$

$$\sum_{m}\sum_{h} X_{m}^{h} \leq NX \tag{77}$$

$$\sum_{d}\sum_{h} Y_{d}^{h} \leq NY \tag{78}$$

$$\sum_{d}\sum_{h} O_{d}^{h} \leq NO, \tag{79}$$

$$\sum_{d}\sum_{h} \mu_{d}^{h} \leq N\mu, \tag{80}$$

$$\sum_z \sum_h \Omega_z^h \le NZ, \tag{81}$$

$$\begin{aligned} PRR_{kpqt} &\le [(1-\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^o}{2}) + (\frac{\alpha}{2})(\frac{a_{kpqt}^p + a_{kpqt}^o}{2})] \\ &+ \sum_l \delta_{kpqlt}(\frac{l-1}{L-1})[(1-\frac{\alpha}{2})(\frac{b_{kpqt}^m + b_{kpqt}^o - a_{kpqt}^m - a_{kpqt}^o}{2}) + (\frac{\alpha}{2})(\frac{b_{kpqt}^m + b_{kpqt}^p - a_{kpqt}^m - a_{kpqt}^p}{2})] \\ &- ([(1-\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^o}{2}) + (\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^p}{2})])\delta_{kpq1t}, \forall k,p,q,t \end{aligned} \tag{82}$$

$$\begin{aligned} PRR_{kpqt} &\ge [(\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^o}{2}) + (1-\frac{\alpha}{2})(\frac{a_{kpqt}^p + a_{kpqt}^o}{2})] \\ &+ \sum_l \delta_{kpqlt}(\frac{l-1}{L-1})[(\frac{\alpha}{2})(\frac{b_{kpqt}^m + b_{kpqt}^o - a_{kpqt}^m - a_{kpqt}^o}{2}) + (1-\frac{\alpha}{2})(\frac{b_{kpqt}^m + b_{kpqt}^p - a_{kpqt}^m - a_{kpqt}^p}{2})] \\ &- ([(\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^o}{2}) + (1-\frac{\alpha}{2})(\frac{a_{kpqt}^m + a_{kpqt}^p}{2})])\delta_{kpq1t}, \forall k,p,q,t \end{aligned} \tag{83}$$

$$\sum_l \delta_{kpqlt} = 1, \forall k,p,q,t \tag{84}$$

$$RE_{kpqt} = \sum_l (\frac{l-1}{l-1}) \times \delta_{kpqlt}, \forall k,p,q,t \tag{85}$$

$$PRR_{kpqt} - (1 - BDK_{dk}) \times N \le PR_{k'pqt} + (1 - BDK_{dk'}) \times N, \forall k,k',d,p,t \tag{86}$$

$$PRR_{k'pqt} - (1 - BDK_{dk'}) \times N \le PR_{kpqt} + (1 - BDK_{dk}) \times N, \forall k,k',d,p,t \tag{87}$$

$$X_m^h, Y_d^h, O_d^h, \mu_d^h, \Omega_z^h, U_f^h, ADK_{dkpt}, BDK_{dkpt}, \delta_{dkpt} \in \{0,1\}, \forall m,d,h,p,t,k,z,f \tag{88}$$

$$\begin{aligned} &QSM_{smit}, QMD_{mdpt}, QDK_{dkpt}, QKD_{kdpt}, QDZ_{dzpt}, QZM_{zmit}, RE_{kpqt}, QDD_{dd'pt}, \\ &PRR_{kpqt}, INV_{dp}, \beta S_{dp} \ge 0, \forall s,m,i,i',p,t,d,k,z,f \end{aligned} \tag{89}$$

4.4. The Suggested fuzzy solution approach

There are numerous methods for solving the multi-objective linear planning models among which the fuzzy planning approaches are increasingly used. The main advantage of the fuzzy approaches over other approaches is that they are able to measure the satisfaction degree from each objective function. This can help the decision-maker to select an efficient approach based on the satisfaction degree and priority from each objective function (Torabi and Hassani, 2008).

Zimmermann presented the first fuzzy approach to solving a multi-objective model called the max-min approach (Zimmerman, 1978); however, the solution obtained by minimizing-maximizing the operator may not be specific and efficient (Lai and Hawang, 1993). In this context, later several approaches were presented in order to compensate for this deficiency. Among the presented approaches, the most appropriate method, which compensates for the deficiencies of the previous fuzzy methods, is a method presented by Hassani and Torabi (2008).

The presented combined method has the following steps:

- The first step: Determine the triangular contingency distribution appropriate for the parameters and formulate the MOILP model for the CLSC design problem.
- The second Step: transform the vague objective functions using the expected value from the vague parameters to their crisp equivalent.
- The third Step: determine the minimum acceptable contingency degree of α decision

vector and convert the fuzzy limitation into its equivalent crisp.

- The fourth Step: determine the ($\alpha - positivePIS$) ideal solution and the ($\alpha - NIS$) $\alpha - Negative$ ideal solution to each objective function.
- Fifth Step: determine the linear membership function for each objective function as follows:

$$\mu_1(x) = \begin{cases} 1 \\ \dfrac{w_{\max} - w_1}{w_{\max} - w_{\min}} if \quad w_{\min} \le w_1 \le w_{\max} \\ 0 \end{cases} \tag{90}$$

$$\mu_2(x) = \begin{cases} 1 \\ \dfrac{w_2 - w_{\min}}{w_{\max} - w_{\min}} if \quad w_{\min} \le w_2 \le w_{\max} \\ 0 \end{cases} \tag{91}$$

$$\mu_3(x) = \begin{cases} 1 \\ \dfrac{w_3 - w_{\min}}{w_{\max} - w_{\min}} if \quad w_{\min} \le w_3 \le w_{\max} \\ 0 \end{cases} \tag{92}$$

- Sixth Step: Transform the multi-objective model into mono-objective using the adaptive functions of Hassani and Torabi (2008).

The TH aggregate-function is as follows:

$$\begin{aligned} & MAX\lambda(x) = \gamma\lambda_0 + (1-\gamma)\sum_j \phi_j \mu(x) \\ & s.t. \\ & \lambda_0 \le \mu_h(x), h = 1,2,3 \\ & x \in F(x),\ \lambda_0 and \lambda \in [0,1] \end{aligned} \tag{93}$$

F(x) shows the justified area including its crisp equivalent limitation. Also, θ_j and γ show the importance of the j th objective function and the compensating factor. It is noteworthy that the optimized amount from the variable $\lambda_0 = \min_j \{\mu_j(x)\}$ shows the minimum satisfaction degree from the objective functions and TH adaptive functions; in fact, searching for the compensation amount between the minimum operator and the weighted sum operator is based on amount of γ . In other words, decision-makers can obtain the balanced solution through manipulating θ_j and γ parameters based on their properties (Pishvaee and Torabi, 2010).

4.5. Non-Dominated Sorting Genetic Algorithm

Non-dominated sorting genetic algorithm (NSGA-II) is one of the most efficient and famous multi-objective optimization algorithms proposed by Deb et al. (2000). Considering that the mono-objective optimization algorithm finds the optimal solution according to an objective while no separate optimal solution can be found in multi-objective problems, naturally, with a set of finite solutions, the right solutions will be the ones with an acceptable performance towards all objectives. Solving the multi-objective problems with Pareto approach is one of the more complicated problems in solving the multi-objective problems, because no especial optimal solution is usually obtained in these methods (Deb, 2001).

4.5.1. Initialization

The initial information to start the NSGA-II algorithm is as follows:

The initial population size (npop) implies the number of chromosomes that must be maintained in each stage. Probability of crossover operator (P_c) implies the number of parents participating the pair's pool; probability of mutation operator (P_m) implies the number of solutions participating in the mutation process; maximum iteration (max-it).

4.5.2. Chromosome representation

Chromosome of the problem includes 4 parts:
First Part: A matrix with two rows and a column number as much as the customers. The first row determines the number of the distribution centre allocated to each customer, and the second row shows the number of the collection centre allocated to the customers.

3	1	3	2
1	1	3	1

Fig. 2. The example to show the structure of chromosomes

According to figure 2, costumers from the first and third regions receive their goods from the third distribution centre and costumers from the first, second, and forth areas send their return goods to the first collection centre.
Second Part: A matrix with two rows and a column number as much as the distribution centres. The first row defines the type of created centre including zero: the centre has not been established, 1: the centre has been established in distribution form, 2: the centre has been established in collection form, 3: the centre has been established in a crossover form, and the second row shows the capacity level type of the created centre.
Third Part: A matrix and the number of production centres. If the number inside cells of this matrix is zero, it means that the production centre has not been established, and if there is a number other than zero inside the cells of the matrix, it means that the production centre has been established and the number inside the matrix shows the capacity of production centre.
Fourth Part: A matrix and the number of disassembly centres. If the number inside cells of this matrix is zero, it means that the separation centre has not been established, and if there is a number other than zero inside cells of the matrix, it means that the disassembly centre has been established, and the figure inside the matrix shows capacity of separation centre.

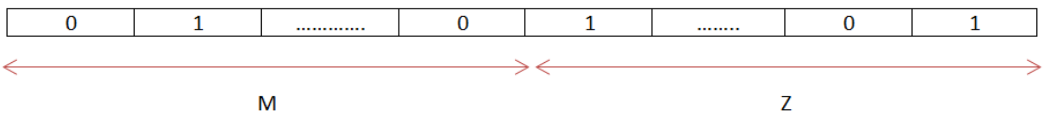

Fig. 3. Chromosome structure for binary variables

4.5.3. Mutation and crossover operators and stop condition of genetic algorithm

For genetic algorithm in both chromosomes of the problem, arithmetic operator has been used for the crossover:

$$ch_1 = round(Paret_1 * Alpha + Paret_2 * (1 - Alpha))$$
$$ch_2 = round(Paret_2 * Alpha + Paret_1 * (1 - Alpha))$$

where $paret_1$ and $paret_2$ are the selected father and mother, respectively, and alpha is a figure between zero and one with the same dimension of chromosome matrixes. Ch_1 and ch_2 are the resulted offspring. Finally, both solutions undergo the rounding process to obtain integers. In this problem, the alpha value has been considered 0.4. The mutation operator applied is also of swap type. Therefore, two genes are selected from the same chromosome and are replaced with each other.

4.5.4. parameter setting

Parameter setting of an algorithm affects its performance and incorrect selection of the algorithm's efficient parameters result in its inefficiency. Therefore, various methods have been used in literature to set the parameter the most popular of which is the experiment design and Response Surface Method. When an algorithm has a large number of parameters, many experiments must be done in order to obtain the optimal levels of the parameters, which are time consuming. For the same reason, we use Taguchi's experiment design method. To set the parameters for each primary demographic factor, the maximum iteration, crossover coefficient, and mutation coefficient, three values have been considered which can be observed in Table 3

Table 3
Amounts intended for npop,Max-it,Pc,Pm

npop	**40**	**50**	**60**
Max-it	65	75	**85**
p_c	0.6	0.7	**0.8**
p_m	0.2	0.3	**0.4**

(S/N) criterion has been used in Taguchi's method. This criterion shows amount of the changes in the solution variable. For each factor, the optimal and appropriate level is the one with higher (S/N) value.

5. Results and Analysis

In order to show the justifiability of the suggested model, several numerical tests have been carried out, and the related results are presented in this section. This problem has been presented in four sizes for each industrial unit, customer area, goods number, and the period numbers in Table4. In addition, Table 5 shows the values of the parameters each of which follows a uniform distribution.

In order to produce the triangular fuzzy parameter values, the model of Hwang and Lai (1992) has been applied. In this model, a three-point fuzzy parameter has been considered for each number that shows the intermediate, pessimistic, and optimistic values.

The (C^m) middle value of each parameter is estimated randomly through uniform distribution first; then, in order to obtain the (C^p) pessimistic and (C^o) optimistic values from each value number, the (r_1,r_2) random interval is considered the values of which range between (0.2,0.8). C^o and C^p values from each ($\tilde{C}$) fuzzy number are obtained as follows:

$$C^o = (1+r_1)\, C^m$$
$$C^p = (1-r_2)\, C^m$$

To compare the possibilistic and crisp models, all the mathematical models are coded in Lingo. A summary of the test results with different α-level is provided in Table 6.

Table 4
The Size of the Tested Problems

TEST PROBLEMS NO.	**1**	**2**	**3**	**4**
NO. OF SUPPLIER CENTRES	2	2	2	3
NO. OF PRODUCTION CENTRES	2	2	3	4
NO. OF DISTRIBUTION CENTRES	3	3	4	5
NO. OF CUSTOMER ZONE	4	4	4	5
NO. OF DISASSEMBLY CENTRES	1	1	1	2
NO. OF RAW MATERIALS	2	2	2	3
NO. OF TYPES OF PRODUCT	1	3	4	4
NO. OF TIME PERIODS	1	4	4	5

Table 5
The Values of the Tested Parameters in Solving the Experimental Problems.

Parameters	Range	Parameters	Range	Parameters	Range
D_{kpt}	U(2100,4200)	H_{dp}	U(5,8)	TCD_{dkpt}	U(2,4)
R_{kpqt}	U(2100,4200)	OC_{dp}	U(4,8)	TCK_{kdpt}	U(2,4)
TD_{dkpt}	U(4,6)	CC_{dp}	U(7,12)	$TCR_{dd\,pt}$	U(2,4)
TE_{kpt}	U(4,8)	CPR_{dp}	U(5,8)	TCZ_{dzpt}	U(2,4)
FCM_{hm}	U(450000,550000)	DC_{fi}	U(3,5)	TCI_{zmit}	U(2,4)
FCD_{hd}	U(170000,210000)	$C\tilde{R}_{zp}$	U(3,5)	$CAPS_{si}$	U(22000,47000)
FCY_{hd}	U(170000,210000)	PR_{pt}	U(200,300)	$CAPM_{hm}$	U(24000,35000)
SC_{hd}	U(170000,210000)	SP_{sit}	U(4,15)	$CAPD_{hd}$	U(20000,26000)
FCZ_{zh}	U(170000,210000)	TCS_{smit}	U(2,4)	$CAPC_{hd}$	U(18000,26000)
C_{mp}	U(90,100)	TCM_{mdpt}	U(2,4)	$CAPE_{hd}$	U(18000,26000)

In order to solve this model, the number of price levels for purchasing the products has been used (|L|); the quality levels (|Q|) and the capacity levels of the facilities (|H|) for all of the problems are fixed and have been respectively considered 5, 2, and 3.

1.5. Solving the presented Model Using TH Fuzzy Approach

In the presented model, first, a value is considered for θ which is the importance coefficient of correlation. Since the first subjective function is of great importance to us, the values for the first to the third objectives have been respectively considered 0.7, 0.1, and 0.2. γ has also been considered 0.5 due to the importance of the first objective function.

Table 6
The Results from the Objective Function Values Using TH Fuzzy Approach

Problem no.	α - value	W_1	$\mu(W_1)$	W_2	$\mu(W_2)$	W_3	$\mu(W_3)$
1	0.6	0.3530887E+10	0.98	26383.75	1	5939.702	0.98
	0.7	0.3390286E+10	0.98	26658.62	1	6285.946	0.98
	0.8	0.2297753E+10	0.98	26933.50	1	7886.283	0.98
	0.9	0.1354032E+10	0.99	27208.38	1	9183.869	0.98
	1	0.123696E+10	0.99	27483.25	1	9405.129	0.98
2	0.6	0.4592026E+11	0.96	256018	0.96	14647.45	0.98
	0.7	0.4481231E+11	0.95	255704.8	0.98	15483.37	0.98
	0.8	45215732	0.98	259789.3	0.98	16312.07	0.98
	0.9	44776988	0.99	261815.6	0.99	16906.05	0.99
	1	44612038	0.99	263579.8	1	17052.97	0.99
3	0.6	0.8483185E+11	0.97	34769.0	0.97	10882.70	0.97
	0.7	0.8457263E+11	0.97	350265.5	0.97	11659.77	1
	0.8	0.845462E+11	0.98	352463.8	0.98	12479.01	1
	0.9	0.84168059E+11	0.99	355192.7	0.99	13305.62	1
	1	0.8369526E+11	1	357930.8	1	14153.92	1
4	0.6	0.956204E+11	0.98	569542.8	1	70876.87	0.98
	0.7	0.9568372E+11	0.98	565757.9	1	79435.91	0.98
	0.8	0.956573E+11	0.99	559813.7	1	78476.34	0.98
	0.9	0.93057948E+11	0.99	555612.8	0.99	76543.86	0.98
	1	0.92565478E+11	1	555423.6	0.99	765432.60	0.98

Since this problem is NP-hard and an exact solution is not available for large-scale with LINGO, a meta-heuristic algorithm was developed to solve it (Karbasian et al., 2011). Table 7 represents computational results obtained from NSGA-II meta-heuristic algorithm for 12 numerical examples.

Table 7
Computational results obtained from NSGA-II meta-heuristic algorithm

Row	s	m	d	k	z	i	p	t	W_1	W_2	W_3
1	2	2	3	4	1	2	1	1	3.622E+10	277.66	142263.64
2	3	3	3	4	2	2	2	2	1.097E+10	1999.14	483576.32
3	3	3	3	5	3	2	2	3	2.608E+10	3810	659140.46
4	4	4	4	6	3	3	3	3	4.394E+10	6470.54	1804735.36
5	5	5	5	10	3	3	3	3	4.927E+10	7080.5	1530364.04
6	7	7	7	15	4	3	3	4	9.717E+10	13707.45	4516956
7	8	10	10	20	5	3	3	4	2.2677E+11	33761	11417936.28
8	10	10	15	25	10	3	4	8	4.065E+11	62306.3	23205133.37
9	10	15	15	30	10	3	4	8	7.648E+11	123702.69	43522699.26
10	10	18	18	40	10	5	8	10	6.381E+11	105152.54	21097967.84
11	15	20	20	50	10	5	8	10	8.5921E+11	134592.24	54416897.32
12	20	20	25	70	15	5	8	10	2.1032E+12	2013576.2	81236994.12

Table 8
Percentage of the Returned Products within periods

period	T_1		T_2		T_3		T_4		T_5		T_6		T_7		T_8	
Problem1	50%	100%	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Problem2	91%	83%	91%	85%	-	-	-	-	-	-	-	-	-	-	-	-
Problem3	100%	89%	100%	87%	100%	90%	-	-	-	-	-	-	-	-	-	-
Problem4	85%	82%	85%	84%	87%	84%	-	-	-	-	-	-	-	-	-	-
Problem5	87%	80%	89%	83%	90%	85%	92%	85%	-	-	-	-	-	-	-	-
Problem6	100%	82%	99%	78%	100%	84%	97%	85%	-	-	-	-	-	-	-	-
Problem7	100%	75%	100%	79%	100%	83%	99%	84%	95%	72%	97%	80%	95%	79%	100%	87%
Problem8	85%	62%	90%	65%	92%	75%	95%	77%	100%	82%	90%	80%	90%	79%	92%	80%
Problem9	85%	73%	79%	65%	82%	77%	80%	75%	78%	64%	85%	80%	90%	79%	85%	82%
Problem10	100%	80%	99%	82%	100%	83%	100%	85%	96%	87%	94%	85%	95%	85%	93%	87%
Problem11	85%	73%5	90%	75%	92%	79%	91%	83%	89%	84%	95%	87%	95%	89%	93%	90%
Problem12	85%	65%	87%	72%	87%	73%	84%	72%	90%	80%	100%	85%	95%	82%	97%	83%

Percentage of the returned products with each quality level for each production type and in each period of time can be observed in table 8.

Figure 5 indicates the Pareto solutions of the model, and assures that the model works efficiently and effectively.

As observed in Table 8, by offering the financial incentive to the customers, most of them tend to return the used products, and this applies to both the products with the quality level 1 and the products with quality level 2. Another remarkable point is the tendency to return the product in each period of time that increases compared to the previous period. Figure 5 shows the percent returns for problem 8.

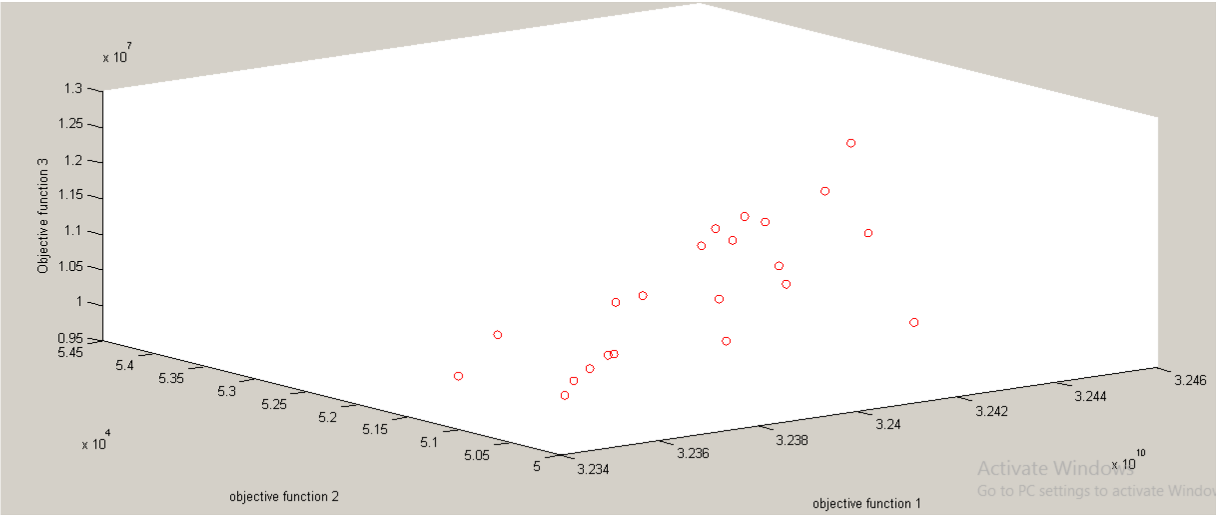

Fig. 5. The Pareto solution solved by NSGA-II

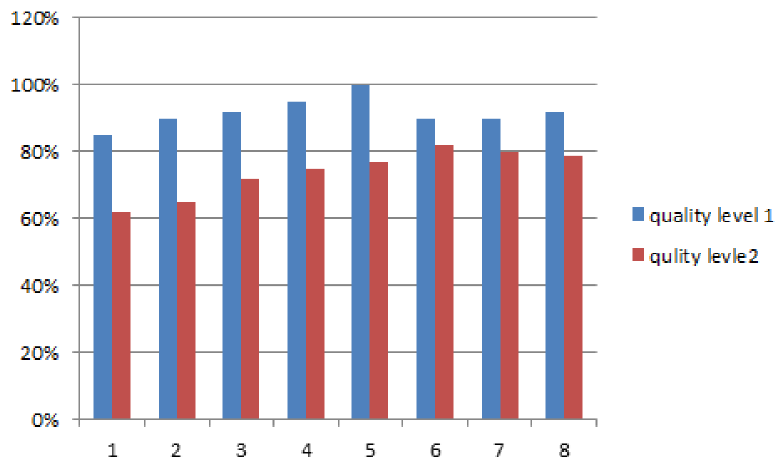

Fig. 6. Percent of returns for problem8

6. Conclusion

The proposed model is a new mathematical planning framework for a multi-level, multi-period and multi-product capacity-bearing integrated SC problem including three objectives. The framework of the network has been designed based on a push-pull strategy in a way that discusses the periodic inventory policies by the distribution centres, namely the inventory level; then, the customer orders are checked during the intervals and the required policies are applied. Moreover, having combined facilities by combining the distribution and collection centres in one place reduce not only the economic expenses, but also the environmental pollutions. In addition, another feature is that since the returned products are divided into two groups, some of them are recycled, some others are repaired, and the repaired products are transferred from collection centres to the distribution centres. Hence, considering the combined centres, a product can be distributed in the place in which it has been repaired; this means that we have transferred them in the same level; this is the novelty of this work separating it from others in this respect. Another characteristic of this work which differentiates it from other works done in this field is the amount of the products returned from the customers which is usually a certain number in the conducted researches, while, in the real world, the producer likes the used productions belonging to the customers to be returned so that they not only fulfil their duties toward the environments by reducing the environmental pollutions, but also are able to benefit the most from the residual values of the used products. Therefore, in order to achieve this goal in this research, it was decided to encourage the customers to return the used goods by offering financial incentives to them. However, it is worth noting that the price offered to the customer is always either equal with the residual value of the product or less. As said earlier, it can be concluded that the main limitation of this research is the determination of the purchase price of the products based on their quality level according to which the percentage of the returned products can be calculated. In this research, in order to reduce the complexity of the model presented by transforming the model into a non-linear one, the model was turned into a linear model by dividing the purchase price into separate levels. However, another complication of this model was the uncertainty in parameters. In order to overcome the problem, the parameters were considered as fuzzy, and then, the uncertain models were turned into certain models using Jimenez's model; since the model is a three-objective one, in order to turn it into a mono-objective one through studying the previous works and comparing them with each other, the TH method presented by Torabi and Hassani (2008) was applied. The presented integrated SC model was solved using Lingo software version8, and some numerical examples were made for analysis and justifiability of the model. NSGA-II algorithm was used to solve the large-size model. The calculative results of efficiency and effectiveness of the model were presented.

The model presented in this paper was adopted from the model presented by keyvanshokooh *et al.* (2013). The difference from previous work is in the network design. In addition, the parameters provided by keyvanshokooh *et al* were deterministic, while, in this paper, parameters are uncertain; hence, the fuzzy approach was used to deal with it. On the other hand, the model presented in this paper is of multi-objective type.

There are some potential future works. Firstly, time complexity is not addressed in this paper; however, this issue might be important for large-sized problems; therefore, developing other heuristic solution methods is suggested in this respect. Additionally, social and environmental aspects are not addressed in this paper; therefore, incorporating the social and environmental aspects into this model can be considered as another attractive future research.

References

Akçali, E., Çetinkaya, S., Üster, H. (2009). Network design for reverse and closed-loop supply chains: an annotated bibliography of models and solution approaches, Networks, 53, 232-238.

Altiparmak F, Gen M, Lin L, Paksoy T. (2006). A genetic algorithm approach for multi- objective optimization of supply chain networks. *Computers and Industrial Engineering*.51,197–216.

Amiri, A. (2006). Designing a distribution network in a supply chain system: formulation and efficient solution procedure, European *Journal of Operational Research*, 171, 567-576.

Aras, N., Aksen, D. (2008). Locating collection centres for distance- and incentive-dependent returns. *International Journal of Production Economics*. 111, 316-333.

Bagherinejad, J., Dehghani, M., (2016), A Non-dominated Sorting Ant Colony Optimization Algorithm Approach to the Bi-objective Multi-vehicle Allocation of Customers to Distribution Centres, *Journal of Optimization in Industrial Engineering ,19, 61-73*

Bandyopadhyay ,S., Bhattacharya, R., (2014). Solving a tri-objective supply chain problem with modified NSGA-II algorithm, *Journal of Manufacturing Systems*, 33 , 41– 50.

Deb, K., Agrawal, S., Pratab, A., and Meyarivan, T., "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-Objective Optimization: NSGA-II. In Schoenauer", M., Deb, K., Rudolph, G., Yao, X., Lutton, E., Merelo, J. J., and Schwefel, H.P., editors, Proceedings of the Parallel Problem Solving from Nature VI Conference, (2000), 849-858, Paris, France. Springer.

Dubois, D., Fargier, H., Fortemps, P., (2003). Fuzzy scheduling: modelling flexible constraints vs. coping with incomplete knowledge, *Eur. J. Oper. Res*. 147, 231–252.

El-Sayed, M., Afia, N., El-Kharbotly, A., (2010), A stochastic model for forward-reverse logistics network design under risk. *Computers & Industrial Engineering*. 58, 423_31.

Fleischmann, M., Beullens, P., Bloemhof-Ruwaard, JM., &Wassenhove, L. (2001), The impact of product recovery on logistics network design. Production and Operations Management, 10, 156-173.

Franca, R.B., Jones, E.C., Richards, C.N., Carlson, J.P., (2009). Multi-objective stochastic supply chain modeling to evaluate tradeoffs between profit and quality, *Int. J. Product. Econ*. 127, 292-299.

Guide, V.D.R., Teunter, R., van Wassenhove, L.N. (2003). Matching demand and supply to maximize profits from remanufacturing, Manufacturing and Service Operations Management, . 5, 303–316.

Guillen, G. Mele, F.D. Bagajewicz, M.J. Espuna, A. Puigjaner, L., (2005). Multiobjective supply chain design under uncertainty, *Chem. Eng. Sci*. 60, 1535–1553.

Hassanzadeh Amin,S., Zhang, G. (2013). A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return. *Applied Mathematical Modelling*, 37, 4165–4176.

Jayaraman, V., Patterson, R., Rolland, E., (2003). The design of reverse distribution networks: Models and solution procedures. *European Journal of Operational Research,* 150. 128–149.

Jayaraman, V., Guide, V. D. R, Jr, Srivastava, R., (1999). A closed-loop logistics model for remanufacturing. Journal of the *Operational Research Society*. 50, 497–508.

Jimenez, M., Arenas, M., Bilbao, A. and Guez, M. V. (2007). Linear programming with fuzzy parameters: an interactive method resolution, *European Journal of Operational Research*, 177, 1599-1609.

Jimenez, M., (1996), Ranking fuzzy numbers through the comparison of its expected intervals, *International Journal of Uncertainty, Fuzziness and Knowledge Based Systems*, 4 (4), 379–388.

Karbasian, M., Dashti, M., 2011. Designing four multi-objective models for dispersion facilities location problems considering Data Envelopment Analysis and maximum covering. *International Journal of Management Science and Engineering Management.* 6, 298-306.

Keyvanshokooh, E., Fattahi, M., Seyed-Hosseini, S.M., Tavakoli-Moghaddam, R., (2013), A dynamic pricing approach for returned products in integrated forward/reverse logistics network design, *Applied Mathematical Modelling*, 37(24), 10182-10202

Klibi, W., Martel, A. Guitouni, A. (2010). The design of robust value-creating supply chain networks: a critical review, *European Journal of Operational Research,* 203. 283–293.

Ko, H.J., Evans, G.W., (2007), A genetic-based heuristic for the dynamic integrated forward/reverse logistics network for 3PLs, *Comput. Oper. Res*. 34, 346–366.

Krikke, HR., Van Harten, A., Schuur, PC., (1999), Reverse logistic network re-design for copiers. OR *Spectrum* , 21. 381–409.

Lai, Y.J., Hwang, C.L., (1993), Possibilistic linear programming for managing interest rate risk, *Fuzzy Sets and Systems.* 54 , 135–146.

Lai, Y.J., Hwang, C.L., (1992), A new approach to some possibilistic linear programming problems, *Fuzzy Sets Syst*. 49, 121–133.

Lee, D. & Dong, M. (2008). A heuristic approach to logistics network design for end-of lease computer products recovery. Transportation Research Part E. 44, 455-474.

Listes, O., Dekker, R., (2005), A stochastic approach to a case study for product recovery network design, *Eur. J. Oper. Res.*160, 268–287.

Marı´n,A, PelegrinB, (1998), There turn plant location problem: modelling, and resolution. *European Journal of Operational Research,* 104(2), 375–392.

Meade, L., Sarkis, J., & Presley A. (2007). The theory and practice of reverse logistics. *International Journal of Logistics System Management*, 3, 56–84.

Meepetchdee Y, Shah N. (2007) Logistical network design with robustness and complexity considerations. International *Journal of Physical Distribution & Logistics Management*.37, 201–22.

Melachrinoudis E, Messac A, Min H. (2005). Consolidating a warehouse network: a physical programming approach. *International Journal of Production Economics*.97,1–17.

Min, H., Ko, H.J., Ko, C.S., (2006), A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns. Omega, 34. .5–69.

Min, H., Ko, H.J., (2008), The dynamic design of a reverse logistics network from the perspective of third-party logistics service providers, *Int. J. Product. Econ.* 113. 176–192.

Pishvaee, M.S., Torabi, S.A. (2010). A possibilistic programming approach for closed-loop supply chain network design under uncertainty. *Fuzzy sets and systems,*161, 2668–2683.

Pishvaee., M.S., Zanjirani Farahani, R., Dullaert, W. (2010). A memetic algorithm for bi-objective integrated forward/reverse logistics network design. Computers & Operations Research. 37, 100–1112.

Pishvaee, M.S., Jolai, F., Razmi, J. (2009). A stochastic optimization model for integrated forward/reverse logistics network design. *Journal of Manufacturing Systems.* 28, 107_114.

Pishvaee, M.R., Kianfar, K., Karimi, B., (2010), Reverse logistics network design using simulated annealing, *Int. J. Adv. Manuf. Technol*. 47, 269–281.

Ramezani. M., Bashiri, M., Tavakkoli-Moghaddam, R., (2013). A new multi-objective stochastic model for a forward/reverse logistic network design with responsiveness and quality level. *Applied Mathematical Modelling.* 37. 328–344.

Sabri, EH, Beamon, BM. (2000). A multi-objective approach to simultaneous strategic and operational planning in supply chain design. Omega. 28,581–98.

Saffari,H., Makui, A., Mahmoodian, V., Pishvaee, M.S.(2015). Multi-objective robust optimization model for social responsible closed-loop supply chain solved by non-dominated sorting genetic algorithm, *Journal of Industrial and Systems Engineering,* 8,(3), 42-59

Salema, M.I.G., Barbosa-Povoa, A.P., Novais, A.Q., (2007), An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty, *Eur. J. Oper. Res*. 179. 1063–1077.

Salema, M.I., Po'voa, A.P.B., Novais, A.Q., (2006), A warehouse-based design model for reverse logistics, *J. Oper. Res. Soc*. 57 (6). 615–629.

Selim, H. Ozkarahan, I. (2008), A supply chain distribution network design model: an interactive fuzzy goal programming-based solution approach, *Int. J. Adv. Manuf. Technol*. 36 , 401–418.

Torabi, S.A., Hassini, E., (2008), An interactive possibilistic programming approach for multiple objective supply chain master planning. *Fuzzy Sets and Systems,* 159, 193–214.

Tsiakis P, Papageorgiou LG. (2008). Optimal production allocation and distribution supply chain networks. *International Journal of Production Economics.*111:468–83.

Uster, H., Easwaran,G., Elif Akcali, E., Sila Cetinkaya,S., (2007), Benders decomposition with alternative multiple cuts for a multi-product closed-loop supply chain network design model. *Naval Research Logistics.* 54. 890–907.

Wang, H.F., Hsu, H.W., (2010), A closed-loop logistic model with a spanning-tree based genetic algorithm, *Comput. Oper. Res.* 37 . 376–389.

Zimmermann, H. J. (1996), Fuzzy set theory and its applications. 3rd. Ed. Kluwer Academic Pub, Boston.

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

This article can be cited: Avakh Darestani, S. & Pourasadollah, F. (2019). A Multi-Objective Fuzzy Approach to Closed-Loop Supply Chain Network Design with Regard to Dynamic Pricing. *Journal of Optimization in Industrial Engineering*. 12 (1), 173- 194.

http://www.qjie.ir/article_538505.html
DOI: 10.22094/joie.2018.476.0