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Research Paper

A Social Engineering Optimizer Algorithm for a Closed-Loop Supply Chain System with Uncertain Demand

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Abstract

This paper presents a new model for a closed-loop supply chain problem under uncertainty. This model considers production, distribution, collection, recycling and disposal of items simultaneously. Because of the increased importance of the environmental factors, this model focuses on the revers flow of the supply chain and considers different types of technology for recycling centers. The model aims to minimize the establishment cost of centers, shipment cost, holding cost, collection cost and recycling cost. To face with uncertain parameters, a credibility-based possibilistic programming method is applied. Then, a social engineering optimizer algorithm is proposed to solve the problem efficiency. To validate the model and proposed algorithm, the results are compared with the results of GAMS. In addition, they prove the superiority of the proposed algorithm over a genetic algorithm to deal with problems and find better results in less running time. Finally, the behavior of the model is assessed by changing the values of parameters and the results are reported.

Keywords: Closed-loop supply chain; uncertainty; social engineering optimizer

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1. Introduction

In recent years, Supply Chain (SC) systems were investigated precisely due to the importance of financial issues and limitation of resources. In this regard, a Closed-Loop Supply Chain (CLSC) is related with forward and revers flows in a SC system. CLSC is related to the strategic and tactical decisions and covers the location, production, distribution and routing of a system to reduce the cost [Baghalian et al., 2013]. Today's companies face with a competitive situation, thus minimizing the related costs of a system can be critical to survive. On the other hand, environmental issues receive more attention during the recent years, which make the situation more complicated [Pishvaee et al., 2012]. A CLSC can be integrated with green issues, since its reverse flow is about recycling, reproduction and disposal of unnecessary materials [Devika et al., 2014].

Obviously, some parameters have an uncertain and unpredictable nature in real situation problems and this point is important for CLSC studies in order to be more practical. Classical studies of a CLSC problem have considered that all the parameters are known and have a constant value; however, it is obvious that this assumption is not practical and many parameters may change during the time. Different factors can be regarded as the reasons of inaccuracy of the parameters including lack of historical data, dynamic nature of parameter and unforeseen actions affecting the value of a parameter. There are two main approaches to face with an uncertain mathematical programming model. In the first approach, each parameter receives a specific value with a pre-determined probability dividing the parameter into different scenarios. In the second approach, intervals of likely various are defined and confined within a probability or possibility distribution function. Briefly the first approach is applicable when an unpredictable event (e.g., disruption) affects the whole system while the second one is useful for dealing with uncertain parameters.

Many studies have considered uncertainty in a CLSC problem including stochastic modeling [Azaron et al., 2008; Zeballos et al., 2014], robust modeling [Pishvaee et al. 2011; Hatefi and Jolai, 2014; Kim et al., 2018] and fuzzy mathematical modeling [Pishvaee and Torabi, 2010; Wu et al., 2018]. In addition, there are some studies merging the application of robust and fuzzy uncertainty approaches to face with uncertain parameters [Tavakkoli-Moghaddam et al., 2016]. Risk is one of the prevalent issues related with the CLSC and receives lots of attention during last years. To deal with uncertainties of the CLSC problem by considering risk, [Mulvay et al., 1995] proposed robust stochastic programming and defined different types of scenarios for uncertain parameters. Next, [Leung et al., 2007] continued this study and developed a robust optimization model for production planning problem and aimed to reduce the related expenditures of the system. Another version of possibilistic programming was developed by [Pishvaee et al., 2012]. In this problem, two objective functions were considered to reduce the total costs and increase the responsibility of system, respectively.

As mentioned before, location and routing problems are two main pillars of a CLSC problem and many studies have considered an integrated location-routing problem to minimize the related costs of the system. [Nadizadeh and Hosseini Nasab, 2019] developed a location-routing problem for revers flow of a SC problem to decrease the routing distance and establishing costs. They used a greedy clustering method to solve their problem. [Ghatreh Samani and Hosseini-Motlagh, 2017] proposed a two-echelon location-routing problem and assumed that there was a middle depot between the beginning point and destination. They applied a fuzzy programming approach to deal with uncertainty and used a combined meta-heuristic method to solve the problem. Since inventory is related with the SC, considering inventory in the SC makes sense. [Nikkhah Qamsari et al., 2017] introduced an inventory-routing problem and used a hybrid heuristic approach to decrease the shipment and holding costs of the system.

[Hosseini-Motlagh et al., 2018] designed a SC system considering the contract between supplier and retailer, inventory level and transportation decisions in which the supplier determined the lead time of delivery and considered two types of shipment modes including fast and slow transportation modes. As shown in the literature review, a CLSC is related with location, production, inventory and routing problems. Many researchers have considered all or some of this problem to develop a new version of SC problems and have utilized different types of meta-heuristics to solve it [Soleimani et al., 2017; Iassinovskaia et al., 2017; Hiassat et al., 2017; Torkaman et al., 2017]. The literature shows there are some gaps in the context of CLSC problem as described below:

- Developing a CLSC by considering production, distribution, collection, recycling and disposal centers in the structure of the system simultaneously.
- Integrating the strategic and tactical decisions including the location, production, inventory and shipment problems alongside with capacity constraints of the proposed centers separately.
- Developing an objective function by considering the price of produced and reproduced items besides the costs of the system.
- Including the effect of the technology type on the quality and price of the recycled items.
- Considering the environmental effects of the forward and reverse logistic flows.
- Considering the social effects of facility establishment on the system.
- Considering the effects of disruption on the system.
- Proposing a new meta-heuristic algorithm to solve a CLSC problem.

The proposed study answers the following concerns:

- Finding the number of items shipped from production centers to distribution centers.
- Finding the number of items shipped from distribution centers to collection centers.
- Finding the number of items shipped from collection centers to recycling and disposal centers.
- Finding the number of items shipped from collection centers to recycling and disposal centers.
- Finding the number of produced items in production centers.
- Determining the inventory level in the distribution centers.
- Determining the number of scraped items to be recycled by considering the technology level of recycling centers.
- Analyzing the effect of technology type on the economic aspects of the CLSC problem.
- Analyzing the effect of parameters variations on the results as the managerial insight.
- Showing the efficiency of the proposed Social Engineering Optimizer (SEO) algorithm to deal with large sized problems.

According to the literature review and the highlighted research gaps, this paper develops a new uncertain capacitated closed-loop supply chain problem by taking into account the location-allocation, inventory balance and shipment decisions alongside with storage limitations of the centers. Including both of the disposal and recycling centers in the system, considering different types of technology for recycling centers, designing an objective function to calculate the income of produced and recycled items, considering the quality and price of the reproduced items, applying the SEO algorithm to solve the problem efficiency and considering the uncertainty of some parameters are the major contributions of this study. The rest of paper is organized as follows. The model is described in Section 2. The uncertain model is converted to crisp model in Section 3. The solution method is described in Section 4. Section 5 reports the results of experiments and Section 6 is related to conclusion.

2. Problem Description

In this problem, an SC is comprised of production, distribution, recycle and disposal centers and the model is developed for a single product, multi-period system. There are some suppliers providing raw materials and some manufacturing centers producing items by recycled materials. Then, these items are shipped to customers through distribution centers.

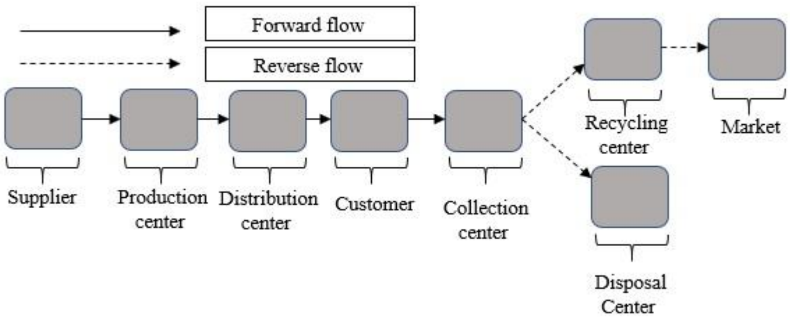

Figure 1. Framework of the considered CLSC

In the next step, the produced items are transported to recycling and disposal centers after separating them in a collection center. The model decides about the number of disposal and recycled items. In addition, the model decides about the quality and price of recycled items by determining the technology type of recycling centers. In other words, recycling centers with a better technology type are able to reproduce the items with higher quality and price. Considering different types of technology in a structure of recycling centers increases the flexibility of the CLSC system. Figure (1) shows the schematic view of the proposed system.

In this regard, the main assumptions of the problem are described below:

- The cost of raw materials includes the price of materials and shipment from a supplier to a production center.
- Some parameters including costs are uncertain. The locations are fixed.
- The customers' demand determines the number of scraped items.
- The collection cost includes the inspection cost of items.
- The recycling centers with higher technology levels are able to reproduce the scraped items with better qualities and higher prices.

2.1. Indices and parameters

Indices:

a	Index of suppliers
b	Index of raw materials
i	Index of potential production centers
j	Index of potential distribution centers
c	Index of customers
k	Index of collection centers
r	Index of recycling centers
d	Index of disposal centers
l	Index of technology types
t	Index of time periods

Parameters*:*

$\boldsymbol{dem_{ct}}$	Demand of customer *c*
$\boldsymbol{Ra_b}$	Number of raw materials needed to produce an item
$\boldsymbol{Fp_i}$	Establishment cost of production center *i*
$\boldsymbol{Fd_j}$	Establishment cost of distribution center *j*
$\boldsymbol{Fc_k}$	Establishment cost of collection center *k*
$\boldsymbol{Fr_{rl}}$	Establishment cost of recycling center *r* with technology *l*
$\boldsymbol{Fdp_d}$	Establishment cost of disposal center *d*
$\boldsymbol{Tr_{ij}}$	Shipment cost from production center *i* to distribution center *j*
$\boldsymbol{Tr_{jc}}$	Shipment cost from distribution center *j* to customer *c*
$\boldsymbol{Tr_{kr}}$	Shipment cost from collection center *k* to recycling *r*
$\boldsymbol{Tr_{kd}}$	Shipment cost from collection center *k* to disposal center *d*
$\boldsymbol{Trm_{jc}}$	Shipment cost of materials from distribution center *j* to customer *c*
$\boldsymbol{Pri_{abt}}$	Cost of material *b* from supplier *a* in time *t*
$\boldsymbol{Pri_c}$	Cost of scraped items related to customer *c*
$\boldsymbol{pro_i}$	Production cost of items in manufacturing center *i*
$\boldsymbol{Clc_{ck}}$	Gathering cost of scraped items for customer *c* in collection center *k*
$\boldsymbol{Rec_{brl}}$	Recycling cost of items for material *b* in recycling center *r* with technology *l*
$\boldsymbol{Slp_{bt}}$	Price of material *b*
$\boldsymbol{Hol_j}$	Holding cost in distribution center *j*
$\boldsymbol{Mcap_{ab}}$	Capacity of supplier *a* for material *b*
$\boldsymbol{Mcap_i}$	Capacity of production center *i*
$\boldsymbol{Mcap_j}$	Capacity of distribution center *j*
$\boldsymbol{Mcap_k}$	Capacity of collection center *k*
$\boldsymbol{Mcap_{rbl}}$	Capacity of recycling center *r* with technology *l* for material *b*
$\boldsymbol{Mcap_d}$	Capacity of disposal center *d*
$\boldsymbol{\eta_c}$	Percentage of scraped items related to customer *c*
$\boldsymbol{\eta_r}$	Percentage of recyclable items
$\boldsymbol{\eta_d}$	Percentage of unrecyclable items
$\boldsymbol{Aco_b}$	Number of recyclable items related to material *b*
$\boldsymbol{Wei}$	Weight of unrecyclable items
$\boldsymbol{Pec_c}$	Cost of unsatisfied demand related to customer *c*
$\boldsymbol{\omega_{1,2,3,4}}$	Coefficient determining the effect of disruption on the capacity of different centers
$\boldsymbol{\tau_{1,2,3,4}}$	Coefficient determining the amount of emitted greenhouse gas due to shipment of items
$\boldsymbol{CO_{1,2,3,4,5}}$	Maximum amount of emitted greenhouse gas
$\boldsymbol{\delta_{job}}$	Coefficient determining the amount of created jobs by opening a new facility
$\boldsymbol{Mjob}$	Minimum number of created jobs

Variables:

$\boldsymbol{z_{aibt}}$	Number of material *b* shipped from provider center *a* to manufacturing center *i* at specific time period
$\boldsymbol{z_{ijt}}$	Number of items shipped from manufacturing center *i* to delivery center *j* at time *t*
$\boldsymbol{z_{jct}}$	Number of items shipped from delivery center *j* to client *c* at time *t*
$\boldsymbol{zi_{ckt}}$	Number of items shipped from customer *c* to collection center *k* at time *t*
$\boldsymbol{zi_{krlt}}$	Number of items transported from gathering center *k* to reusing center *r* by specific technology *l* at time *t*
$\boldsymbol{yi_{brilt}}$	Number of material *b* shipped from recycling center *r* with technology *l* to production center *i* at time *t*
$\boldsymbol{Si_{brlt}}$	Number of sold items of b for recycling center *r* with technology *l* to at time *t*
$\boldsymbol{Di_{cdt}}$	Number of disposals shipped from gathering center *k* to disposal center *d* at time *t*
$\boldsymbol{In_{jt}}$	Inventory level of delivery center *j* at time *t*
$\boldsymbol{V_i}$	1 if production center *i* is active; 0, otherwise
$\boldsymbol{H_j}$	1 if distribution center *j* is active; 0, otherwise
$\boldsymbol{Q_k}$	1 if collection center *k* is active; 0, otherwise
$\boldsymbol{U_{rl}}$	1 if recycling center *r* is active; 0, otherwise
$\boldsymbol{E_d}$	1 if disposals center *d* is active; 0, otherwise

2.2. Problem formulation

$$\text{Min } z = \sum_i Fp_i V_i + \sum_j Fd_j H_j + \sum_k Fc_k Q_k + \sum_r Fr_{rl} U_r + \sum_d Fdp_d E_d + \sum_{t,i,j} pro_i z_{ijt} \quad (1)$$

$$\sum_{b,l,t,k,r} Rec_{brl} zi_{krlt} + \sum_{t,a,b,i} Pri_{abt} z_{aibt} + \sum_{t,c,k} Pri_c zi_{ckt} - \sum_{t,b,r,l} Slp_{bt} Si_{brlt} + \sum_{t,c,k} Clc_{ck} zi_{ckt} + \sum_{t,i,j} Tr_{ij} z_{ijt} + \sum_i Hol_j In_{jt} +$$

$$\sum_{t,c,k} Pri_c z_{jct} + \sum_{t,j,c} Tr_{jc} z_{jct} + \sum_{t,c,d} Tr_{kd} Di_{cdt} + \sum_{b,t,r,i,l} Tr_{jc} yi_{brilt}$$

s.t.

$$\sum_i Ra_b z_{ijt} = \sum_i z_{aibt} + \sum_{r,l,t} yi_{brilt} \quad \forall b,j,a \quad (2)$$

$$In_{jt-1} + \sum_i z_{ijt} = In_{jt} + \sum_c z_{jct} \quad \forall t,j,a \quad (3)$$

$$\sum_j z_{jct} \geq \widetilde{dem}_{ct} \quad \forall t,c \quad (4)$$

$$\sum_k zi_{ckt} \leq \eta_c \, \widetilde{dem}_{ct} \quad \forall t,c \quad (5)$$

$$\sum_{k,r,l,t} zi_{krlt} = \sum_{c,k} \eta_r zi_{ckt} \quad \forall t \quad (6)$$

$$\sum_k Aco_b zi_{krlt} \geq \sum_i yi_{brilt} + Si_{brlt} \quad \forall b,r,l,t \quad (7)$$

$$\sum_d Di_{cdt} = \sum_k Wei.\eta_d.zi_{ckt} \quad \forall t,c \quad (8)$$

$$\sum_i z_{aibt} \leq \widetilde{Mcap}_{ab} \omega_1 \quad \forall t,a,b \quad (9)$$

$$\sum_j z_{ijt} \leq \widetilde{Mcap}_i V_i \omega_2 \quad \forall t,i \quad (10)$$

$$\sum_c z_{jct} \leq \widetilde{Mcap}_j H_j \omega_3 \quad \forall t,j \quad (11)$$

$$\sum_c zi_{ckt} \leq \widetilde{Mcap}_k Q_k \omega_4 \quad \forall t,k \quad (12)$$

$$\sum_i yi_{brilt} + Si_{brlt} \leq \widetilde{Mcap}_{rbl} U_r \quad \forall t,b,r,l, \quad (13)$$

$$\sum_k Di_{kdt} \leq \widetilde{Mcap}_d E_d \quad \forall t,d \quad (14)$$

$$\sum_l U_{rl} \leq 1 \quad \forall r,d \quad (15)$$

$$\sum_{a,i,b,t} z_{aibt} \tau_1 \leq CO_1 \quad (16)$$

$$\sum_{i,j,t} z_{ijt} \tau_2 \leq CO_2 \quad (17)$$

$$\sum_{j,c,t} z_{jct} \tau_3 \leq CO_3 \quad (18)$$

$$\sum_{c,k,t} z_{ckt} \tau_4 \leq CO_4 \quad (19)$$

$$\sum_{k,r,l,t} z_{krlt} \tau_5 \leq CO_5 \quad (20)$$

$$\sum_i (V_i + H_j) \delta_{job} \geq Mjob \quad (21)$$

The first equation of developed model is related to the total costs of the system including facility opening, production and recycling, shipment, inventory and supplying raw materials. Constraint (2) is about the flow stability between facilities. Constraint (3) makes sure that the summation of incoming flow and remaining inventory of the previous periods are equal to the flow related to the distribution centers and inventory of the present time. Equation (4) ensures that the demands are satisfied. Constraint (5) states the relation between demand and the number of scraped products requiring to be investigated in the collection centers. Equation (6) indicates that the number of scraped items are equal at recycling center and collection centers. Constraint (7) obliges that the number of incoming recycled items to manufacturing centers are equal to the number of scraped items at collection centers. Constraint (8) ensures that the number of disposable items are equal at both collection and disposing centers. Constraints (9)-(14) are related to the capacity constraints of the system considering the effect of disruption on the capacity of facilities. Constraint (15) ensures that each recycling center is able to receive one technology. Constraints (16) - (20) force the system to produce no more than determined amount of greenhouse gas due to shipment of items. Constraint (21) considers the minimum number of created jobs by opening facility centers.

3. Equivalent Crisp Model

Considering the strategic and tactical decisions of the model, it is crucial to implement a credibility based fuzzy programming and get the counterpart crisp model. Because of the vague and subjective nature of some parameters

$$\boldsymbol{Cr}\ (\tilde{\alpha} \geq r) = \frac{1}{2}(\sup \mu(x)_{x \leq r} + 1 - \sup \mu(x)_{x \geq r}) \quad (25)$$

$$\boldsymbol{Cr}\ (\tilde{\alpha} \leq r) \geq \alpha \leftrightarrow\ r\ \geq (2 - 2\alpha)\alpha^3 + (2\alpha - 1)\alpha^4 \quad (26)$$

$$\boldsymbol{Cr}\ (\tilde{\alpha} \geq r) \geq \alpha \leftrightarrow\ r\ \leq (2 - 2\alpha)\alpha^2 + (2\alpha - 1)\alpha^1 \quad (27)$$

$$\boldsymbol{Cr}\ (\tilde{B}x = y) \geq \pi \equiv\ B_2 x \leq y \leq B_3 x \quad (28)$$

and lack of knowledge, the experts are asked to determine the variation range of some parameters. In addition, due to the future predictions of uncertain parameters, data are necessarily uncertain and according to their nature, preferably have to be considered possiblistic [e.g., see Peidro et al. 2009]. Possiblistic parameters in the model can be shown with four prominent values, therefore,

$$\boldsymbol{Cr}\ (\tilde{\alpha} = r) \geq \pi \equiv\ \boldsymbol{Cr}\ (\tilde{\alpha} \geq r) \geq \frac{\pi}{2} \cap \boldsymbol{Cr}\ (\tilde{\alpha} \leq r) \geq \frac{\pi}{2} \quad (29)$$

trapezoidal possiblistic distribution is fitted for them. To clarify in what way the distribution

$$\boldsymbol{Cr}\ (\tilde{\alpha} = r) \geq \pi \equiv\ \boldsymbol{Cr}\ (\tilde{\alpha} \leq r) \leq \frac{(2-\pi)}{2} \cap \boldsymbol{Cr}\ (\tilde{\alpha} \leq r) \geq \frac{\pi}{2} \quad (30)$$

$$\begin{aligned} &\text{Min } E\ (Obj) = \ E(\frac{c_1 + c_2 + c_3 + c_4}{4})x \\ &\text{s.t.} \\ &Ax \geq (2 - 2\alpha)d_3 + (2\alpha - 1)d_4 \\ &A'x \leq (2\beta - 1)c_1 + (2 - 2\beta)c_2 \\ &B_3 x \geq y \\ &B_2 x \leq y \\ &x, y \geq 0 \end{aligned} \quad (31)$$

for the parameters could be demarcated see [Inuiguchi et al., 2000]. The theoretical model is described in Model (22). Model (23) depicts the possibilistic programming based on credibility degree. In the proposed study, possibilistic programming is defined according to the credibility degree.

$$\begin{aligned} &\textbf{Min } \boldsymbol{Obj} = \ \tilde{c}x \\ &\text{s.t.} \\ &Ax \geq \tilde{d} \\ &A'x \leq \tilde{c} \\ &\tilde{B}x = y \\ &x.y \geq 0 \end{aligned} \quad (22)$$

$$\begin{aligned} &\textbf{Min } E\ (Obj) = \ E(\tilde{c})x \\ &\text{s.t.} \\ &\boldsymbol{Cr}\ (Ax \geq \tilde{d}) \geq \alpha \\ &\boldsymbol{Cr}\ (A'x \leq \tilde{c}) \geq B \\ &\boldsymbol{Cr}\ (\tilde{B}x = y) \geq \pi \\ &x, y \geq 0 \end{aligned} \quad (23)$$

In this regard a credibility based possibilistic programming is described [Liu and Liu, 2002]: Let $\tilde{\alpha} = (a^1, a^2, a^3, a^4)$ be a trapezoidal fuzzy number and *r* be a real number.

$$E(\tilde{\alpha}) = \int_0^{\infty} \boldsymbol{Cr}\ (\tilde{\alpha} \geq r)dr - \int_{\infty}^{0} \boldsymbol{Cr}\ (\tilde{\alpha} \leq r)dr \quad (24)$$

Because $\tilde{\alpha}$ is a trapezoidal fuzzy number, so, $E\ (\tilde{\alpha}) = \ E(\frac{\alpha^1+\alpha^2+\alpha^3+\alpha^4}{4})$, is obtained from equation (24). Credibility measures are as follows:

Based on Equation (24) [Zhu and Zhang, 2009] showed, if $\alpha \geq 0.5$ then we can write:

Proposition: To achieve crisp model, Equation (28) can be applied.

Proof: Obviously, while a fuzzy number is equal to a real number, credibility degrees of the fuzzy number being bigger and smaller than real number, are identical. Also, Expression (29) can be described as follow:

Regarding Equations (26) and (27), when $\alpha^2 \leq r \leq \alpha^3$, $Cr\ (\tilde{\alpha} \leq r) = Cr\ (\tilde{\alpha} \geq r) = 0.5$ is correct.

Finally, the crisp version of model (23) is as follows:

And the uncertain parts of main model are converted to crisp model as follows:

4. Solution Approach

Due to NP-hardness of logistic network design problem [Eckert and Gottlieb, 2002; Jo et al., 2007], exact approaches need plenty of time to solve the problem. Here, we apply the SEO algorithm introduced by [Fathollahi-Fard et al., 2018] to deal with large-sized test problems. They showed the efficiency of the SEO algorithm to deal with SC problems. In this regard, we show the accuracy of the SEO algorithm and feasibility of the model by comparing the results of the SEO algorithm with GAMS solver for small sized instances. In addition, due to inability of exact solver to solve large-sized instances, the results of the SEO algorithm are compared with GA to prove the efficiency of the SEO algorithm in dealing with large-sized instances.

$$\sum_k zi_{ckt} \le (dem_{ct(1)}(2\beta - 1) + dem_{ct(2)}(2 - 2\beta))\eta_c \quad (32)$$

$$\sum_j z_{jct} \ge dem_{ct(3)}(2 - 2a) + dem_{ct(2)}(2a - 1) \quad (33)$$

$$\sum_i z_{aibt} \le Mcap_{ab(1)}(2\beta - 1) + Mcap_{ab(2)}(2 - 2\beta) \quad (34)$$

$$\sum_j z_{ijt} \le (Mcap_{i(1)}(2\beta - 1) + Mcap_{i(2)}(2 - 2\beta))V_i \quad (35)$$

$$\sum_c z_{jct} \le (Mcap_{j(1)}(2\beta - 1) + Mcap_{j(2)}(2 - 2\beta))H_j \quad (36)$$

$$\sum_c zi_{ckt} \le (Mcap_{k(1)}(2\beta - 1) + Mcap_{k(2)}(2 - 2\beta))Q_k \quad (37)$$

$$\sum_i yi_{brilt} + Si_{brlt} \le (Mcap_{rbl(1)}(2\beta - 1) + Mcap_{rbl(2)}(2 - 2\beta))U_r \quad (38)$$

$$\sum_k Di_{kdt} \le (Mcap_{d(1)}(2\beta - 1) + Mcap_{d(2)}(2 - 2\beta))E_d \quad (39)$$

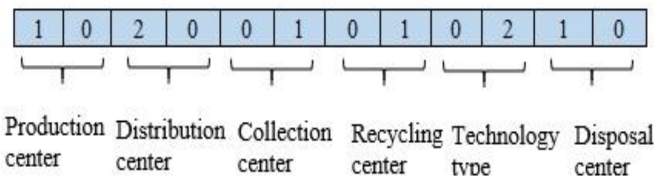

Figure 2. An example of a person

4.1. Solution representation

To implement the SEO algorithm, each person determines whether a center can be established in a candidate place or not. The traits of this person specify the main decisions about manufacturing sites, delivery sites, gathering sites, reusing sites, technology type of reprocessing sites and disposal sites respectively. Figure 2 demonstrates a person for an example with size of $[I \times J \times K \times R \times L \times D]$ = $[2 \times 2 \times 2 \times 2 \times 2 \times 2]$. Based on this Figure, plant 1 can be open at location 4. Other traits also, can be paraphrased as the previous example. To take into account the amount of production shipped to other centers a person array is designed which convert the random numbers between [0 1] to the appropriate values. Also, a penalty function is applied for the capacity constraints of the model.

4.2. Social engineering optimizer

This algorithm considers a solution as a person with different features and traits. In this regard, abilities of that person represent the variables of the solution. In the first step of this algorithm, two random solutions are generated and divided into attacker and defender based on their results. Next, the traits of defender are tested to train the attacker solution. The attacker solution aims to assess the other solution by copying and replacing a variable on the defender solution. In the next step, the order of variables related to defender are changed and the fitness of new defender solution is calculated. The position of attacker and new defender are replaced if the new defender reach a better result. It should be note that, being local search or exploitation search in this algorithm depends to the training and retraining between two generated solutions. To intensify the exploitation phase, the defenders should be ignored and generate new ones.

There are four techniques to conduct attack strategy including obtaining, phishing, diversion theft, respond to attack. Obtaining method misuse the defender solution to generate new solutions and reach the determined objectives. In phishing method, the solution selected as the attacker feign to approach the defender while the defender solution changes it places and moves toward the required place of attacker. In the diversion theft, attacker lead the defender to a fake place as a trick strategy, this method generates only one new solution. Within this method, the attacker achieves some positive traits of the defender to reach the desired objective. Figure 3 shows the pseudo-code of this algorithm. It should be mentioned that the fourth attacking techniques are selected to deal with this problem.

4.3. Genetic algorithm

To compare and evaluate the performance of the proposed SEO algorithm, GA is applied which is widely used in CLSC problems [Sim et al, 2004; Soleimani et al, 2013; Huang et al, 2016]. Mutation and crossover are the main operators of the GA to search the solution area and generate new solutions. It should be noted that, in GA a solution is represented as a chromosome while in SEO each solution is considered as a person. Mutation and crossover are designed to implement local search and global search in solution space. In this regard, crossover is related to local search while mutation intensifies the global search of algorithm.

```
Start;
Generate attacker and defender
Set iteration = 1;
While run time < Max-time
        Keep on training and retraining.
        Set Number of attackers = 1;
        While Number of attackers < Max-attackers
        Act on attack
        Check the feasibility
        React to attack;
        If the OF of defender< OF of attacker
        Change the situation of attacker and defender
        Endif
        Generate new solution as defender
        iteration = 1+ iteration;
End while
```

Figure 3. Pseudo-code of the SEO algorithm

There are different types of crossover and mutations and here single point cross over and two-point mutation are implemented. In a single point crossover method, two parents are selected randomly and a particle of their chromosomes is marked to replace the position of this parents and generate new solutions. In this method the child is dependent to its parents and inherit its features from them which means this method generate solutions with low range of diversification. In a two-point mutation method, one parent is selected randomly and two points are marked in the chromosome to replace the position of gens in the chromosome and generate new solutions. This method is less pertinent to the initial solutions and covers a wider area of solution space which means this method strengthens the global search.

5. Computational Results

Here some test problems are developed and experimented to compare the outcomes of the meta-heuristic algorithms using MATLAB software. Due to mixed integer nature of the model the problem is codded in GAMS software by using CPLEX solver. Experiments are conducted on a personal computer with Core i5 processor and 6GB RAM. First, the results of exact solution method (CPLEX) with the results of the meta-heuristic algorithms are compared to be ensured about the validity of the model and proposed algorithms. Next, the outcomes of the proposed meta-heuristics are analyzed. The parameters of model are set based on Table 1. Since the main parameters of metaheuristics are determinative and effects on the performance of this algorithms, the major values of metaheuristics are tuned using a Response Surface Methodology (RSM).

Table 2 shows the results of comparison between optimal solution and mentioned algorithms (i.e., SEO and GA). The comparative results of SEO and GA instances with larger dimensions are described in Table 3. To show the results and compare the difference between algorithms in small-sized and large-sized test problems, $[100 \times$

$(\mathrm{G_{Alg}} - \mathrm{G_{Opt}})/\mathrm{G_{Alg}}]$ and $[100 \times (\mathrm{S_{GA}} - \mathrm{S_{SEO}})/\mathrm{S_{GA}}]$ are utilized respectively. $\mathrm{G_{Opt}}$ and $\mathrm{G_{Alg}}$ denotes the value of GAMS and proposed algorithms. According to the results reported in the Table 2, both of SEO and GA algorithms are able to reach results near to the Exact solver. However, Table 3 shows the superiority of SEO to reach results with better quality based on the GAP % metric $[100 \times (S_{\mathrm{GA}} - S_{\mathrm{SEO}})/S_{\mathrm{GA}}]$. In addition, Table 3 shows SEO algorithm requires less time to solve large-sized instances.

5.1. Sensitivity analysis

Following, the ninth test problem is selected and parameters are determined based on the Table 1. Also, GAMS software is used to analyze the model. First, the sensitivity analysis is performed on the possibilistic parameters (α and β), which are the credibility measures of the proposed credibility based fuzzy programming approach (see Section 3), to assess the optimality of model under different conditions. Figure 4 shows the results of objective function under the variability of (β). This Figure shows that, increasing the value of β leads to lower amounts of OFV. Figure 5 shows the results of objective function under the variability of (α). This Figure shows that, increasing the value of α leads to higher amounts of OFV. Next, three parameters of model are selected and the result of OFV is assessed by changing the value of this parameters. These parameters include establishment cost of distribution center (Fd_j), Shipment cost from distribution center to customer (Tr_{jc}) and holding cost of distribution centers (Hol_j). In this regard, Figure 6 shows the changes of OFV due to variation of Fd_j. It also shows that increasing the establishment cost enhances the total costs of CLSC. In this situation model decides to establish distribution centers leading to higher transportation costs.

Figure 7 demonstrates the effects of Tr_{jc} changes on the system cost and Figure 8 depicts the effects of Hol_j variations on the system cost. It also shows that, shipment cost has a direct relationship on the OFV, however, the slop increasing is less than the increasing rate of the previous figure.

Table 1. Source of the parameters

Parameters	Values	Parameters	Values
$\widetilde{dem}_{ct}$	$\sim U(9070.10085.12465.15500)$	Hol_j	$\sim U(40.120)$
Ra_b	$\sim U(6.11)$	$\widetilde{Mcap}_{ab}$	$\sim U(180000.200000.220000.250000)$
Fp_i	$\sim U(224000.241000)$	$\widetilde{Mcap}_i$	$\sim U(20000.25000.30000.32000)$
Fd_j	$\sim U(12500.13000)$	$\widetilde{Mcap}_j$	$\sim U(18000.20000.25000.27000)$
Fc_k	$\sim U(11000.12000)$	$\widetilde{Mcap}_k$	$\sim U(20000.22000.25000.27000)$
Fr_{rl}	$\sim U(105000.120000)$	$\widetilde{Mcap}_{rbl}$	$\sim U(200000.250000.300000.320000)$
Fdp_d	$\sim U(11000.13000)$	$\widetilde{Mcap}_d$	$\sim U(250000.280000.310000.380000)$
Tr_{ij}	$\sim U(65.86)$	η_c	$\sim U(0.7.0.9)$
Tr_{jc}	$\sim U(45.75)$	η_r	$\sim U(0.85.0.9)$
Tr_{kr}	$\sim U(35.66)$	η_d	$\sim U(0.15.0.1)$
Tr_{kd}	$\sim U(15.35)$	Aco_b	$\sim U(6.8)$
Trm_{jc}	$\sim U(65.86)$	Wei	$\sim U(21.23)$
Pri_{abt}	$\sim U(55.78)$	Pec_c	$\sim U(10.13)$
Pri_c	$\sim U(200.300)$	Slp_{bt}	$\sim U(500.720)$
pro_i	$\sim U(460.510)$	Rec_{brl}	$\sim U(30.44)$

$\omega_{1,2,3,4}$	$\sim U(0.7.1)$	$CO_{1,2,3,4,5}$	$\sim U(1000.2000)$
$\tau_{1,2,3,4}$	$\sim U(1.5.3)$	δ_{job}	$\sim U(30.40)$
Clc_{ck}	$\sim U(105.125)$	$Mjob$	$\sim U(60.100)$

Table 2. Comparison of SEO and GA with Gams results in case of run time and results for instances with small dimensions (α, β = 0.6)

						SEO		GA	
Dataset	*i*	*j*	*k*	*r*	*d*	Gap (%)	Time	Gap (%)	Time
1	4	5	2	1	1	0	47	0	54
2	4	5	2	1	1	0.004	51	0.008	63
3	5	7	2	1	1	0.005	59	0.01	68
4	5	7	3	2	2	0.12	61	0.2	73
5	6	7	3	2	2	0.2	67	0.32	82
6	6	9	3	2	2	0.5	71	0.7	90
7	7	9	5	3	3	0.65	76	0.9	98
8	7	9	5	3	3	0.74	81	1.1	101
9	7	8	7	6	4	1.01	90	1.24	110
10	10	12	7	5	4	1.2	97	1.76	117

Table 3. Comparison of run time and results for instances with large dimensions in SEO and GA (α, β =0.6)

						SEO vs. GA		
Dataset	i	j	k	*r*	*d*	Gap (%)	Time (SEO)	Time (GA)
11	11	20	10	8	6	2	125	152
12	11	30	10	8	6	3.1	198	201
13	13	35	12	10	8	4.5	225	241
14	15	40	12	10	8	6.1	321	351
15	17	45	15	11	10	7.8	410	422.5
16	20	50	15	12	10	8.5	495	510
17	30	55	18	12	12	9	512	535
18	35	60	18	15	12	10	601	645
19	40	65	20	20	15	11.4	655	712
20	45	70	20	20	20	13.5	711	801

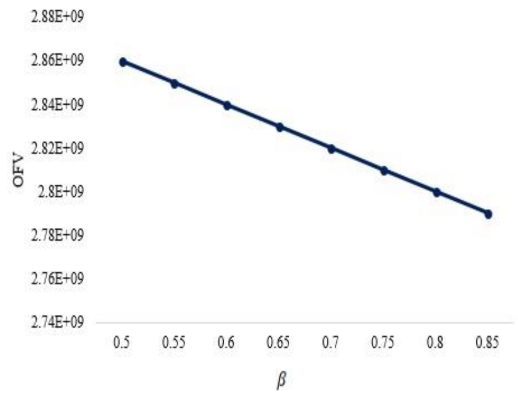

Figure 4. OFV of the model with variability of $\boldsymbol{\beta}$

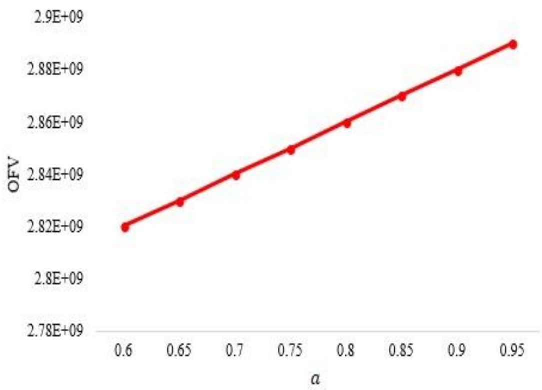

Figure 5. OFV of the model with variability of $\boldsymbol{\alpha}$

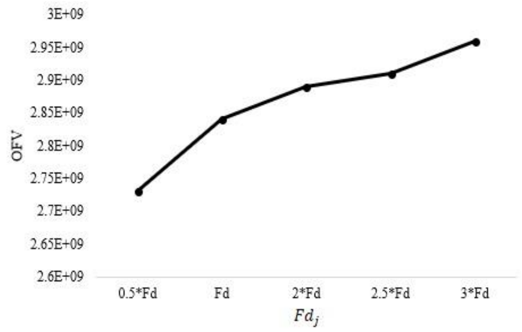

Figure 6. OFV of model with variability of establishment cost

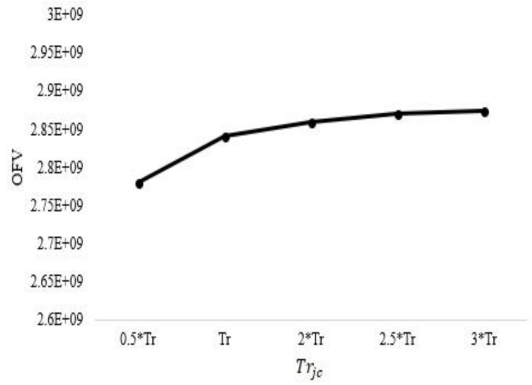

Figure 7. OFV of model with variability of shipment cost

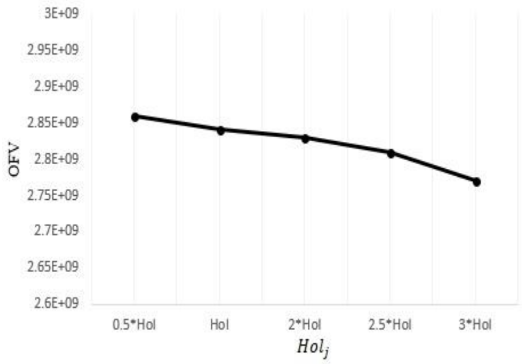

Figure 8. OFV of model with variability of inventory cost

Based on Figure 8, the inventory cost has an indirect relationship with the OFV. By enhancing the inventory cost, model decides to assign less number of items from production center to distribution center leading to less shipment and inventory costs. Although, it can increase the penalty of unsatisfied demand.

6. Conclusion

Considering economic factors of a supply chain, we proposed a model for a CLSC network with removal centers and reusing sites. In this regard the model takes into account the establishment cost of manufacturing sites, delivery sites, gathering sites, removal sites and reusing sites. The transportation cost between centers, inventory holding cost and unsatisfied demand are regarded in order to bring the model closer to the operational space. A credibility based possibilistic programming method is applied, to face with uncertain parameters of the problem. Due to NP-hardness of the problem a SEO method is used to deal with large sized problems. In the next step, some instances are proposed to assess the behavior of the model, validate the feasibility of the model and report the variation of objective function under the different values of parameters. Also, the performance of the proposed SEO algorithm is assessed, where the outcomes proved the superiority of developed SEO algorithm in comparison to the GA. Some extensions on this study could be interesting and worthy to follow as the future study. Regarding pricing policies for a CLSC alongside the other economic aspects of the system can be a motivating topic. Additionally, considering other exact methods, hybrid metaheuristics and implementing the model on a real case are good suggestions for future studies.

7. References

- Azaron, A., Brown, K. N., Tarim, S. A., Modarres, M. (2008) "A multi-objective stochastic programming approach for supply chain design considering risk ", International Journal of Production Economics, Vol.116, No. 1, pp. 129-138.

- Baghalian, A., Rezapour, S. and Farahani, R. Z. (2013) "Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case " , European Journal of Operational Research, Vol. 227, No. 1, pp. 199-215.

- Devika, K., Jafarian, A., Nourbakhsh, V. (2014). "Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques ", European Journal of Operational Research, Vol. 235, No. 3, pp 594-615.

- Eckert, C., Gottlieb, J. (2002,). "Direct representation and variation operators for the fixed charge transportation problem." International Conference on Parallel Problem Solving from Nature (pp. 77-87). Springer, Berlin, Heidelberg.

- Fathollahi-Fard, A. M., Hajiaghaei-Keshteli, M., Tavakkoli-Moghaddam, R. (2018) "The Social Engineering Optimizer (SEO) " ,Engineering Applications of Artificial Intelligence, Vol. 72, pp 267-293.

- Ghatreh Samani, M., Hosseini-Motlagh, S. M. (2017). " A Hybrid algorithm for a two-echelon location-routing problem with simultaneous pickup and delivery under fuzzy demand", International Journal of Transportation Engineering, Vol. 5, No. 1, pp 59-85.

- Hatefi, S. M., Jolai, F. (2014). " Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions ", Applied Mathematical Modelling, Vol. 38, No. 9–10, pp 2630-2647.

- Hiassat, A., Diabat, A., Rahwan, I. (2017). " A genetic algorithm approach for location-inventory-routing problem with perishable products ", Journal of Manufacturing Systems, Vol. 42, pp 93-103.

- Hosseini-Motlagh, S. M., Ebrahimi, S., Nami, N., Ignatius, J. (2018). " Supply chain coordination through lead time crashing in a socially responsible supply chain considering transportation modes and carbon emissions tax ", International Journal of Transportation Engineering, Vol. 6, No. 4, pp. 331-354.

- Huang, M., Yi, P., Guo, L., Shi, T. (2016). "A modal interval based genetic algorithm for closed-loop supply chain network design under uncertainty", IFAC-PapersOnLine, Vol. 49, No. 12, pp. 616-621.

- Iassinovskaia, G., Limbourg, S., Riane, F. (2017). " The inventory-routing problem of returnable transport items with time windows and simultaneous pickup and delivery in closed-loop supply chains ", International Journal of Production Economics, Vol 183, pp 570-582.

- Inuiguchi, M., Ramık, J. (2000). "Possibilistic linear programming: a brief review of fuzzy mathematical programming and a comparison with stochastic programming in portfolio selection problem ", Fuzzy Sets and Systems, Vol 111, No 1, pp 3-28.

- Jo, J. B., Li, Y., Gen, M. (2007). "Nonlinear fixed charge transportation problem by spanning tree-based genetic algorithm ", Computers & Industrial Engineering, Vol 53, No 2, pp 290-298.

- Kim, J., Do Chung, B., Kang, Y., Jeong, B. (2018). " Robust optimization model for closed-loop supply chain planning under reverse logistics flow and demand uncertainty ", Journal of Cleaner Production, Vol 196, pp 1314-1328.

- Leung, S. C., Tsang, S. O., Ng, W. L., Wu, Y. (2007). "A robust optimization model for multi-site production planning problem in an uncertain environment ", European Journal of Operational Research, Vol 181, No 1, pp 224-238.

- Liu, B., Liu, Y. K. (2002). "Expected value of fuzzy variable and fuzzy expected value models ", IEEE Transactions on Fuzzy Systems, Vol. 10, No. 4, pp 445-450.

- Mulvey, J. M., Vanderbei, R. J., Zenios, S. A. (1995). " Robust optimization of large-scale systems ", Operations Research, Vol. 43, No. 2, pp 264-281.

- Nadizadeh, A., Hosseini Nasab, H. (2019). " Modelling and solving the capacitated location-routing problem with simultaneous pickup and delivery demands ", International Journal of Transportation Engineering, Vol.6, No. 3, pp217-235.

- Nikkhah Qamsari, A., Hosseini Motlagh, S. M., Jokar, A. (2017). " A two-phase hybrid heuristic method for a multi-depot inventory-routing problem " , International Journal of Transportation Engineering, Vol. 4, No. 4, pp 287-304.

- Peidro, D., Mula, J., Poler, R., Verdegay, J. L. (2009). " Fuzzy optimization for supply chain planning under supply, demand and process uncertainties " , Fuzzy Sets and Systems, Vol. 160, No. 18, pp. 2640-2657.

- Pishvaee, M. S., Rabbani, M., Torabi, S. A. (2011). " A robust optimization approach to closed-loop supply chain network design under uncertainty " , Applied Mathematical Modelling, Vol. 35, No. 2, pp. 637-649.

- Pishvaee, M. S., Razmi, J., Torabi, S. A. (2012). "Robust possibilistic programming for socially responsible supply chain network design: A new approach ", Fuzzy Sets and Systems, Vol 206, pp 1-20.

- Pishvaee, M. S., Torabi, S. A. (2010). " A possibilistic programming approach for closed-loop supply chain network design under uncertainty ", Fuzzy Sets and Systems, Vol. 161, No 20, pp. 2668-2683.

- Sim, E., Jung, S., Kim, H., Park, J. (2004, June). "A generic network design for a closed-loop supply chain using genetic algorithm " , Genetic and Evolutionary Computation Conference (Vol. 3103pp. 1214-1225). Springer, Berlin, Heidelberg.

- Soleimani, H., Govindan, K., Saghafi, H., Jafari, H. (2017). " Fuzzy multi-objective sustainable and green closed-loop supply chain network design " , Computers & Industrial Engineering, Vol 109, pp 191-203.

- Soleimani, H., Seyyed-Esfahani, M., Shirazi, M. A. (2013). " Designing and planning a multi-echelon multi-period multi-product closed-loop supply chain utilizing genetic algorithm ", The International Journal of Advanced Manufacturing Technology, Vol. 68, No. 1–4, pp 917–931.

- Tavakkoli-Moghaddam, R., Raziei, Z., Tabrizian, S. (2016). " Solving a bi-objective multi-product vehicle routing problem with heterogeneous fleets under an uncertainty condition", International Journal of Transportation Engineering, Vol. 3, No. 3, pp 207-225.

- Torkaman, S., Ghomi, S. F., Karimi, B. (2017). "Multi-stage multi-product multi-period production planning with sequence-dependent setups in closed-loop supply chain ", Computers & Industrial Engineering, Vol. 113, pp. 602-613.

- Wu, G. H., Chang, C. K., Hsu, L. M. (2018). " Comparisons of interactive fuzzy programming approaches for closed-loop supply chain network design under uncertainty", Computers & Industrial Engineering, Vol.125, pp. 500-513.

- Zeballos, L. J., Méndez, C. A., Barbosa-Povoa, A. P., Novais, A. Q. (2014). "Multi-period design and planning of closed-loop supply chains with uncertain supply and demand " ,Computers & Chemical Engineering, Vol. 66, pp 151-164.
- Zhu, H., Zhang, J. (2009, November). " A credibility-based fuzzy programming model for APP problem ", International Conference on Artificial Intelligence and Computational Intelligence (AICI'09), (Vol. 1, pp. 455-459). IEEE.