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Original Article

Developing an Integrated Closed-Loop Supply Chain Model By Considering Social Responsibility and Solving the Model Using Meta-Heuristic Methods

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Abstract

The present study provided an integrated closed-loop supply chain model by considering social responsibility and solved the model with the application of meta-heuristic methods of particle swarmoptimization and NSGA-II. First, a three-objective mathematical model was presented with the following aims: 1) Minimizing the supply chain costs, 2) Maximizing social responsibility or social benefits, and 3) Minimizing the environmental effects. Furthermore, the experimental sample problems were solved in three groups of small, medium and large by particle swarm algorithm. The results of solving this algorithm were compared to the results of solving NSGA-II algorithm basedon quality, diversity, uniformity and solving time comparative parameters to prove the efficiency of this algorithm. The obtained results indicated that particle swarm optimization algorithm always had higher ability to achieve high quality and optimal solutions than NSGA-II algorithm. NSGA-II algorithm had less solving time than particle swarm optimization algorithm and searched the solution space more uniformly.

Key words: Closed-loop supply chain, Social responsibilities, Multi-objective optimization

INTRODUCTION

Supply chain sustainable management was defined as the management of materials, data, and investment for cooperation between companies during the supply chain and has been considered by managers and researchers during the last two decades (Hsueh, 2015). In recent years, sustainability in supply chain management (Hussain and Tiwari, 2015) and considering the environmental factors and social aspects have been important subjects (Brandenburg et al, 2014). Environmental and social sustainability are relatively complicated issues, but they affect the ability of different parts of supply chain by adapting technologies, creating a friendly environment and considering environmental factors (Longoni et al, 2014).

Corporate social responsibility is the moral acceptance of business for achieving the sustainability and includes economic, environmental, and social conditions. Social responsibility is studied based on four aspects: 1) Economic responsibility: It is the most fundamental layer of social responsibility because shareholders demand for the return of their capital; it leads to economic growth and there is a direct relationship between economic growth and financial freedom(Çiftçioğlu and Almasifard, 2015).2) Legal responsibility: Rules must be implemented based on international standards.3) Moral responsibility: organizations must conduct the activities expected by society. 4) Humanitarian responsibility: It is the fourth aspect of social responsibility includingsuch subjects as supporting the poor, preventing risk, reducing energy consumption, protectingnatural resources, preventing pollution, etc. (Zeng et al,2014).

Social responsibility has been converted from small concepts into complicated ones and has influencedorganizational

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decision-making for more than several decades. From an economic standpoint, the lagged value of final consumption expenditure has a significant effect on the share of final consumption expenditure in Gross Domestic Product (Almasifard and Saeedi, 2017). The combination of social responsibility, sustainability, and cost clarification helps shareholders to accept more social responsibility, have self–confidence, and make efforts for new innovations. This strategy has many effects on suppliers and organizational implementation helping to promote the safety of products, technology, and process in terms of environment. When organizations improve programs by implementing social responsibility, they should pay attention to the opinions and needs of shareholders and workers to improve working conditions, health, and job security in the long term (Bijoylaxmi et al, 2015).

The purpose of implementing social responsibility is to create consistency in supply chain, optimize social welfare, and reduce production costs leading to the reduction of price, stimulation of customers for more purchases, and optimization of supply chain profit. Analyzing the effect of social responsibility on 133 Eco-Responsible Spanish companies showed that it has non-economic effects such as organizational liability, creating motivation in employees, customer satisfaction, innovations, energy saving, material recycling, etc.(Reverte et al,2015).

According to previous reviews, few articles used quantitative models for supply chain sustainable management (Reverte et al,2015). Based on the importance of the subject and this research gap, the present study provided the mathematical model of sustainable closed-loop supply chain by considering social responsibility and problem solving by using meta-heuristic algorithms. First, the multi-objective quantitative model was presented to optimize the implementation cost and levels of social responsibility and reduce the environmental effects. Since the sustainable distribution of supply chain is an NP-HARD problem (Panda et al, 2014), the meta-heuristic methods of PSO and NSGA-II were used to solve the model.

REVIEW OF LITERATURE

In recent years, many researchers studied and presented models for closed-loop supply chain. For example, Vahdani (2015) presented a multi-product and multi-period model for designing the closed-loop supply chain network under fuzzy environment. Demirel et al (2014) presented a multi-piece and multi-period hybrid linear planning for a closed-loop supply chain network. Fallah-Tafti et al (2014) in their study designed the supply chain network in an integrated way. Their proposed network is a multi-level network including assembly, customers, and collection and disposal centers.MA et al (2016) presented a bi-objective planning model for closed-loop supply chain under the conditions of uncertainty. They presented a single-objective mathematical model for closed-loop supply chain problem and used LINGO software for problem solving. LINGO could not solve the larger problems because the problem was NP-HARD. Thus, the researchers only solved the smaller problems. Banasik et al (2017) presented the linear planning multi-objective model of closed-loop supply chain for mushroom production. Their model in direct logistics included producer and retailer level butother levelswere not considered. In addition, in reverse logistics, the collection and rehabilitation centers were considered. Hassanzadeh Amin and Baki (2017) presented the multi-objective facility location model in closed-loop supply chain under fuzzy conditions. They modeled the reverse logistics facilitylocation in their model. In addition, there are studies in the field of social responsibility. Hussain et al (2015) used interpretive structural modeling(ISM) and analytical network process (ANP) for evaluating the appropriate alternatives of resources, time, and money in line with economic-environmental and social aspects in supply chain sustainable management. Furthermore, MCarment Suescun (2015) found that many problems are still unknown based on the development of social responsibility area by studying the extractive industries of Latin America and the Caribbean (LAC). Although most mining companies in LAC area accepted the concept of social responsibility due to the increase of social expectations and the ability of establishing relationships with local communities. However, there are some inconsistencies in implementingsocial responsibility due to the non-satisfaction of employees' expectations, fear, distrust, and unknown inconsistencies.

Saeidi et al (2014) studied 250 manufacturers in Iran andthey concluded that there is a direct relationship between social responsibility and organizational programs; they also found a direct relationship between social responsibility and three factors of comparative advantage. Sustainability, liability, and customer satisfaction were considered as the probable intermediatesbetween these two relationships.

MATHEMATICAL MODELING

The network studied in this research is a direct and reverse integrated logistic network that can be applied in industries which can recycle, bury, dispose, remanufacture, and repair the products that are at the end of life products. In the designed model, the return products are divided into recoverable products, remanufacturing products, recyclable products, and products for disposal.

Recoverable products are recovered in collection and rehabilitation centers and can be completely reused after the recovery. These products are sent to distribution centers for sale. Remanufacturing products can be recovered in production centers and enter the production line after the recovery. The products which cannot be used anymore, except in raw materials or convertible materials, are sent to recycling centers. The products which cannot be used anymore, even in raw materials preparation, are sent to burial and disposal centers for secure burial. This network can supporta variety of industries like electronic and digital equipment (computers, cameras, etc.), automotive industries and other similar industries.

Based on the above-mentioned issues, the hypotheses considered for modeling are as follows:

- The model is multi-period and multi-product. In addition, the capacity of all facilities is limited.
- Customer demand and values of return products are certain.
- The place of suppliers and producers are certain and fixed.
- The number is three-dimensional, and the solution space is discrete.
- The number of facilities is not predetermined.
- All customers' demands are responded and all return products are collected.
- The maintenance cost is dependent on the end of period inventory and shortageis not allowed.
- The place of producers, suppliers, and customers is fixed and other places include potential distribution, collection, rehabilitation, recycling, burial, and disposal centers.

Indices, Parameters, and Research Variables

A. Indices

I: Fixed points set for supply centers $i \in I$

J: Fixed points set for production centers $j \in J$

K: Fixed points set for distribution centers $k \in K$

L: Fixed points set for customers $l \in L$

M: Fixed points set for collection and rehabilitation centers $m \in M$

P: Fixed points set for recycling centers $p \in P$

N: Fixed points set for burial and disposal centers $n \in N$

S: set of products $s \in S$

T: time $t \in T$

B. parameters

r_l^{st}: The amount of product s from customer center I at time t

d_l^{st}: The amount of product demand s by customer I at time t

Bj^{st}: Return product rate s from collection and rehabilitation center m to production center j at time t

Bn^{st}: Return product rate s from collection and rehabilitation center m to burial and disposalcenter at time t

Bk^{st}: Return product rate s from collection and rehabilitation center m to distribution center k at time t

Bp^{st}: return product rate s from collection and rehabilitation center m to supply center pat time t

f_k: The fixed costs of constructingthe distribution center at place k

f_m: The fixed costs of constructing the collection and rehabilitation center m at place m

f_p: The cost of constructing the recycling center at place p

f_n: The cost of constructing the burial and disposal at place n

c_{ij}^s: All costs of transporting product s from supplier product I to producer center j

c_{jk}^s: All costs of transporting product s from producer product j to distribution center k

c_{kl}^s: All costs of transporting product s from distribution center k to customer center I

c_{lm}^s: All costs of transporting each return product from customer I to collection and rehabilitation center m

c_{mp}^s: All costs of transporting each return product from distribution and rehabilitation center m to recycling center p

c_{mn}^s: All costs of transporting each return product from distribution center m to burial and disposal center n

c_{mk}^s: All costs of transporting each return product from collection and rehabilitation center m to distribution center k

c_{mj}^s: All costs of transporting each return product from collection and rehabilitation center m to production center j

c_{pj}^s: All costs of transporting each return product from recycling center p to production center j

c_{pi}^s: All costs of transporting each return product from recycling center p to supply center i

cq_{jj}^s: All costs of transporting product s from productioncenter j to its warehouse

cq_{jk}^s: All costs of transporting product s from production warehouse k to distribution center k

ca_i: The capacity of supply center at place i

ca_jThe capacity of production center at place j

ca_{jj}: The capacity of production center at place j

cr_j: The capacity of remanufacturing in production center at place j

ca_k: The capacity of distribution center at place k

cr_kThe capacity of distributing the recovered products in distribution center at place k

cr_i: The capacity of producing raw materials from return products in supply center at place i

ca_m: The capacity of collection and rehabilitation center at place m

ca_pThe capacity of recycling center at place p

ca_n: The capacity of burial and disposal center at place n

h_j^s: The maintenance cost of each product s in production warehouse at place j

α_k: The number of job opportunities created in the k-th distribution center

α_{inv}: The number of job opportunities created in the centers related to reverse logistics

sp_{js}: The average waste created in the j-th production center to produce each unit of product s

dp_{js}: The average dangerous materials used in the j-th j-th production center to produce each unit of product s

θ_w: The weight factor of the produced waste (the weight of produced waste in the objective function)

θ_h: The weight factor of dangerous materials (the weight of dangerous materials in the objective function)

C. Variables

y_{mt}: If the collection and rehabilitation center is established at place m at period t, its value will be 1, otherwise it will be 0.

y_{kt}: If the distribution center is established at place k at period t, its value will be 1, otherwise it will be 0.

y_{pt}: If the recycling center is established at place p, its value will be 1, otherwise it will be 0.

y_{nt}: If the burial and disposal center is established at place n, its value will be 1, otherwise it will be 0.

x_{ij}^{st}: Thestream amount of product s from supply center i to production center j at time t

x_{jk}^{st}: The stream amount of product from production center j to distributioncenter k at time t

Q_{jj}^{st}: The stream amount of product s from production center k to its warehouse at time t

x_{kl}^{st}: The stream amount of product s from distribution center k to customer I at time t

Q_{jk}^{st}: The stream amount of product from production center j to distribution center k at time t

x_{lm}^{st}: The stream amount of return product s from customer I to collection and rehabilitation center m at time t

x_{mk}^{st}: The stream amount of return product s from customer I to collection and rehabilitation center m to distribution center at time t

x_{mp}^{st}: The stream amount of return product s from customer I to collection and rehabilitation center m to recycling center p at time t

x_{mn}^{st}: The stream amount of return product s from customer I to collection and rehabilitation center m to disposal centernat time t

x_{mj}^{st}: The stream amount of return product s from customer I to collection and rehabilitation center m to productioncenter jat time t

x_{pj}^{st}: The stream amount of return product s from recycling center p to production center j at time t

x_{pi}^{st}: The stream amount of return product s from recycling center p to supply center i at time t

U_j^{st}: The amount of remaining product s in production center warehouse j at time t

The Main Structure of the Model

The objective function of the model refers to the minimization of supply chain costs and is defined as equation 1.

$$\min z1=\sum_{t\in T}(\sum_{k\in K} f_k y_{kt}+\sum_{m\in M} f_m y_{mt}+\sum_{p\in P} f_p y_{pt}+ \sum_{n} f_n y_{nt}+\sum_{s\in S}\sum_{i\in I}\sum_{j\in J} c_{ij}^s x_{ij}^{st}+\sum_{s\in S}\sum_{j\in J} cq_{jj}^s Q_{jj}^{st}+ \sum_{s\in S}\sum_{j\in J}\sum_{k\in K} c_{jk}^s x_{jk}^{st}+\sum_{s\in S}\sum_{ij\in J}\sum_{k\in K} cq_{jk}^s Q_{jk}^{st}+\sum_{s\in S}\sum_{k\in K}\sum_{l\in L} c_{kl}^s x_{kl}^{st}+ \sum_{s\in S}\sum_{l\in L}\sum_{m\in M} c_{lm}^s x_{lm}^{st}+\sum_{s\in S}\sum_{m\in M}\sum_{p\in P} c_{mp}^s x_{mp}^{st}+\sum_{s\in S}\sum_{m\in M}\sum_{n\in N} c_{mn}^s x_{mn}^{st}+ \sum_{s\in S}\sum_{m\in M}\sum_{j\in J} c_{mj}^s x_{mj}^{st}+\sum_{s\in S}\sum_{m\in M}\sum_{k\in K} c_{mk}^s x_{mk}^{st}+\sum_{s\in S}\sum_{p\in P}\sum_{i\in I} c_{pi}^s x_{pi}^{st}+ \sum_{s\in S}\sum_{p\in P}\sum_{j\in J} c_{pj}^s x_{pj}^{st}+\sum_{s\in S}\sum_{j\in J} h_j^s U_j^{st}) \quad (1)$$

Second objective function: This target refers to the maximization of social responsibility or social benefits.

$$\max z2=\sum_{t\in T}(\sum_{k\in K}\alpha_k y_{kt}+\sum_{m\in M}\alpha_{inv} y_{mt}+\sum_{p\in P}\alpha_{inv} y_{pt}+\sum_{n\in N}\alpha_{inv} y_{nt}) \quad (2)$$

Third objective function: the reduction of environmental effects

$$\min z3=\theta_w\sum_{t\in T}\sum_{j\in J}\sum_{k\in K}\sum_{s\in S} sp_{js}(x_{jk}^{st}+Q_{jk}^{st})+ \theta_k\sum_{t\in T}\sum_{j\in J}\sum_{k\in K}\sum_{s\in S} dp_{js}(x_{jk}^{st}+Q_{jk}^{st}) \quad (3)$$

Limitations:

$$\sum_{k\in K} x_{kl}^{st}=d_l^{st}\forall l\in L,\forall s\in S,t\in T \quad (4)$$

$$\sum_{m\in M} x_{lm,qs}^{s}=r_l^s\forall l\in L,\forall s\in S, allquality-level \quad (5)$$

Expressions 4 and 5 guarantee that all customers' demands are satisfied in the direct stream, and all return products are collected from customers' centers in the return stream.

$$\sum_{k\in K} x_{mk}^{st}=Bk^{st}\sum_{l\in L} x_{lm}^{st}\forall m\in M,\forall s\in S,t\in T \quad (6)$$

$$\sum_{j\in J} x_{mj}^{st}=Bj^{st}\sum_{l\in L} x_{lm}^{st}\forall m\in M,\forall s\in S,t\in T \quad (7)$$

$$\sum_{i\in I} x_{mi}^{st} = Bi^{st}\sum_{l\in L} x_{lm}^{st} \forall m\in M,\forall s\in S,t\in T \quad (8)$$

$$\sum_{n\in N} x_{mn}^{st} = Bn^{st}\sum_{l\in L} x_{lm}^{st} \forall m\in M,\forall s\in S,t\in T \quad (9)$$

$$\sum_{j\in J}(x_{jk}^{st}+Q_{jk}^{st}) = \sum_{l\in L} x_{kl}^{st} - \sum_{m\in M} x_{mk}^{st} \forall k\in K,\forall s\in S,t\in T \quad (10)$$

$$\sum_{i\in I} x_{ij}^{st} + \sum_{m\in M} x_{mj}^{st} + \sum_{p\in P} x_{pj}^{st} = \sum_{k\in K} x_{jk}^{st} + Q_{jj}^{st} \forall j\in J, \forall s\in S,t\in T \quad (11)$$

$$U_j^{st} = Q_{jj}^{st} - \sum_{k\in K} Q_{jk}^{st} \forall j\in J,\forall s\in S,t\in T \quad (12)$$

Limitations 6 to 12 are related to the stream balance in nodes.

$$\sum_{k\in K} Q_{jk}^{st} \le Q_{jj}^{s} \forall j\in J,\forall s\in S,t\in T \quad (13)$$

Expression 13 guarantees that the amount of output stream from production warehouse is less than the total input to production warehouse.

$$\sum_{s\in S}\sum_{j\in J} x_{ij}^{st} \le ca_i \forall i\in I,t\in T \quad (14)$$

$$\sum_{s\in S}\sum_{k\in K} x_{jk}^{st} + \sum_{s\in S} Q_{jj}^{st} \le ca_j \forall j\in J,t\in T \quad (15)$$

$$\sum_{s\in S}\sum_{l\in L} x_{kl}^{st} \le ca_k y_{kt} \forall k\in K,t\in T \quad (16)$$

$$\sum_{s\in S}\sum_{k\in K} x_{mk}^{st} + \sum_{s\in S}\sum_{j\in J} x_{mj}^{st} + \sum_{s\in S}\sum_{n\in N} x_{mn}^{st} + \sum_{s\in S}\sum_{p\in P} x_{mp}^{st} \le ca_m y_{mt} \forall m\in M,t\in T \quad (17)$$

$$\sum_{s\in S}\sum_{m\in M} x_{mk}^{st} \le cr_k y_{kt} \forall k\in K,t\in T \quad (18)$$

$$\sum_{s\in S}\left(\sum_{m\in M} x_{mj}^{st} + \sum_{p\in P} x_{pj}^{st}\right) \le cr_j \forall j\in J,t\in T \quad (19)$$

$$\sum_{s\in S}\sum_{p\in P} x_{pi}^{st} \le cr_i \forall i\in I,t\in T \quad (20)$$

$$\sum_{s\in S}\sum_{m\in M} x_{mn}^{st} \le ca_n y_{nt} \forall n\in N,t\in T \quad (21)$$

$$\sum_{s\in S}\sum_{m\in M} x_{mp}^{st} \le ca_p y_{pt} \forall p\in P,t\in T \quad (22)$$

$$\sum_{s\in S} U_j^{st} \le ca_{jj} \forall j\in J,t\in T \quad (23)$$

Expressions 14 to 23 guarantee that the stream is only between the points in which feasibility is established and the total stream in feasibility does not exceed its capacity.

$$\sum_{k\in K} y_{kt} \ge 1 \quad (24)$$

$$\sum_{m\in M} y_{mt} \ge 1 \quad (25)$$

$$\sum_{p\in P} y_{pt} \ge 1 \quad (26)$$

$$\sum_{n\in N} y_{nt} \ge 1 \quad (27)$$

Expressions 24 to 27 guarantee that at least one of the potential centers is active.

$$Bk^{st} + Bj^{st} + Bp^{st} + Bn^{st} = 1 \forall s\in S,t\in T \quad (28)$$

Expression 28 guarantees that the total coefficients of return products are equal to 1.

$$y_{mt}, y_{kt}, y_{pt}, y_{nt} \in \{0,1\} \forall m\in M,\forall k\in K, \forall p\in P,\forall n\in N,t\in T \quad (29)$$

$$x_{ij}^{st}, x_{jk}^{st}, Q_{jj}^{st}, U_j^{st}, x_{kl}^{st}, Q_{jk}^{st}, x_{lm}^{st}, x_{mj}^{st}, x_{mk}^{st}, x_{mp}^{st}, x_{mn}^{st} \ge 0 \forall i\in I,\forall j\in J,\forall k\in K,\forall l\in L,\forall m\in M, \forall n\in N,\forall p\in P,t\in T \quad (30)$$

Limitations 29 and 30 are the logical and obvious limitations related to decision variables of the problem.

SOLUTION ALGORITHM

In this study, the multi-objective swarm optimizationalgorithm based on Pareto archive was proposed to solve the model. The proposed structure of multi-objective PSOwas presented to optimize these objective functions considered in the model. The purpose of designing the above method is to achieve more optimal solutions or Pareto. In order to evaluate this algorithm, its output was compared to NSGA-II algorithm based on the comparative parameters of quality, diversity, and uniformity.

Particle Swarm Optimization Algorithm

Here is the general structure designed forhybrid multi-objective PSO method.

{
Generate N feasible solutions as initial population.
Apply improvement procedure for generated particles.
Apply feasibility check procedure for improved particles.
Initialize p_g and p_i.
Initialize the adaptive Pareto archive set so that it is empty.
While a given maximal number of iterations is not achieved
Update particle by eq.(31)
Improve population of particles.
Apply feasibility check procedure.
Evaluate the updated particles to get the new and
Update Pareto archive.
Select N solutions with higher quality and higher diversity as population for next generation.
End while
}
Return Pareto archive.
}

Displaying the solution

In this study, matrix was used to display each solution. Each solution includes several matrices which are designed based on the model's outputs. For example, a two-dimensional matrix with M rows and T columns was defined for y_{mt}. In addition, a four-dimensional matrix with I*J*S*T dimensions was defined for x_{ij}^{st} Thus, the matrix will be defined for other outputs.

Producing the initial solutions

In this study, a neighborhood search method was used to produce initial solutions. In this method, four operators were used in parallel. In each neighborhood search function, one solution was sent to the first step. The relevant operator was applied on the solution to obtain the solution neighborhood. After producing all neighborhood solutions, the solution with higher quality and higher diversity was selected based on Deb rule (2002) and added to the initial solutions population in case of no iteration. Here, the structure of solution search operators is explained.

Operator 1: an index i isproduced randomly in the uniform range [1.m] (m= the number of collection and rehabilitation centers) and if y_m(i) value is one and there are other homes with value 1, y_m(i)value will be changed to zero, and the correction procedure will be applied on the matrices related to this solution to correct them based on the model limitations. If y_m(i) value is 0, it will be converted to 1, and the correction procedure will be applied on other matrices to change them based on limitations.

Operator 2: an index i is produced randomly in the uniform range [1.n] (n= the number of disposal centers) and if y_n(i) value is one, and there are other homes with value 1, y_n(i) value will be changed to zero. If y_n(i) value is 0, it will be changed to 1.

Operator 3: an index i is produced randomly in the uniform range [1.p] (p= the number of recycling centers) and if y_p(i) value is one, and there are other homes with value 1, y_p(i) value will be changed to zero. If y_p(i) value is 0, it will be changed to 1.

Operator 4: an index i is produced randomly in the uniform range [1.k] (k= the number of distribution centers) and if y_k(i) value is one, and there are other homes with value 1, y_k(i) value will be changed to zero. If y_k(i) value is 0, it will be changed to 1.

It should be noted that the correction procedure was applied on other matrices at the end of each explained operator to change them based on limitations.

Improvement procedure

Improvement procedure designed in this study was based on variable neighborhood search (VNS). In this regard, four variable neighborhood structures (NSS) were designed. These structures were combined to VNS structure. The neighborhood search structures (solution) explained in the previous section which was combined to each other as VNS structure is as follows:

{for each input solution s
K=1
While the stopping criterion is met do
S1=Apply mutation type k
S=Acceptance methode(S,S1)
If s is improved then
K=1
Else
K=k+1
If k=5 then
K=1
Endif
End while}

As the above structure shows, the acceptance procedure was applied on the obtained solution and the previous solution after applying the neighborhood search to select one of the two solutions for the next VNS iteration. For the acceptance procedure, the dominated solution was selected among the two solutions by using non-dominated relations.

Updating the particles

Genetic algorithm operators were used to update the particles (Tavakoli Moghadam, 2011). Particles were updated based on the following equation:

$$x_i^{t+1} = (x_i^t - p_i^t) + (x_i^t - p_g^t) + \overline{x_i^t} \tag{31}$$

In the above equation,
x_i^{t+1}: The i-th particle in the t+1th iteration (generation)

x_i^t: The i-th particle in the t+1th iteration
p_i^t: The best solution to which the i-th particle was reached so far (to this generation)
p_g^t: The best solution that has been found so far
$\overline{x_i^t}$: The neighborhood of x_i^t that was produced by mutation operator
'-':The sign of crossover operator
'+': The sign of selection

In fact, five solutions were produced to achieve the i-th solution in the t-1th iteration: two solutions were the results of the crossover operator between x_i^t and p_i^t. Two others were related to the crossover operator on x_i^t and p_g^t, and the other one was the result of applying mutation operator on x_i^t. Finally, among these five solutions, the one with higher diversity and higher quality was selected as x_i^{t+1}. In fact, in this formula p_g^t and p_i^t were used for achieving the solutions of the next iteration.

Crossover operator: The crossover operator designed in this algorithm is a single-point parent. Other variables were produced basedon children and other model limitations.

Mutation operator: The mutation operator used in formula 31 for updating the particles was the same variable neighborhood search (VNS) explained fully in the last section.

Updating p_i^t and p_g^t

For the i-th particle, if there is a neighborhood better than p_i among the neighborhoods found for this solution, p_i will be replaced, otherwise it will remain unchanged. In addition, if the best solution is better than p_g among all solutions found so far, p_g will be replaced;otherwise, it will remain unchanged.

Updating pareto archive

A set called Pareto archive was considered in the proposed algorithm which keeps the non-dominated solutions produced by the algorithm. This set was updated inthe iteration of the algorithm. The produced solutions wereplaced in a solution pool to be ranked. Then, from the pool, the solutions in the first rank or the same non-dominated solutions were selected and considered as the new Pareto archive.

Selecting the solution

In this study, the solutions in the population of the iteration described in 4.1.6and the new solutions produced by the algorithm were placed ina solution pool to select the next iteration population. After ranking and calculating the crowding distance for each solution based on its rank, N solutions with higher quality and higher diversity were selected as the next iteration population of the algorithm by using Deb rule (2002).

COMPUTATIONAL RESULTS

In this study, the particle swarm optimization and NSGA-II algorithms were implemented in MATLAB software to test their efficiency. Then, the obtained results were compared to each other basedon the comparative parameters of quality, uniformity, diversity, and solving time. It should be noted that all computations were done by computer 1TB -R5 M335 4 GB Core.

Comparative Parameters

In this study, three parameters as explained below were studied to make the comparison.

Quality: this parameter compares the quality of Pareto solutions obtained by each method and determines the percentage of solutions at rank 1 belonging to each method. If the percentage increases, the quality of the algorithm will rise.

Spacing: it tests the distribution uniformity of the obtained Pareto solutions in the solutions border. This parameter is defined as follows:

$$s = \frac{\sum_{i=1}^{N-1} \left| d_{mean} - d_i \right|}{(N-1) \times d_{mean}}$$

In the above equation, d_i shows the Euclidean distance between the two adjacent non-dominated solutions and d_{mean} shows the mean values of d_i.

Diversity: this parameter is used for determining the amount of non-dominated solutions found on the optimal border. Diversity is defined as follows:

$$D = \sqrt{\sum_{i=1}^{N} \max(\left\| x_t^i - y_t^i \right\|)}$$

In the above equation, $\left\| x_t^i - y_t^i \right\|$ shows the Euclidean distance between the two adjacent solutions of x_t^i and y_t^i on the optimal border.

Experimental Problems

In this study, several experimental problemswere designed in the groups of small, medium, and large. Since there is no sample problem in the literature to cover all model's parts, some experimental problems of previous studies were selected, and their sample problems were used. Thus, some parameters which were not covered by these studies were selected randomly. Furthermore, the previous studies were reviewed to determine some other experimental problems. Based on the size range of the problems selected in these studies, the experimental problems were designed.

COMPUTATIONAL RESULTS

In order to solve the problems by using PSO and NSGA-II algorithms, the model and algorithm parameters were adjusted as follows:

- The demand amount of customer *I* was considered from product *s* in the uniform range of [50,100].
- The capacity of all supply centers was 6000; the capacity of all production centers was 9000; the warehouse capacity of all manufacturing centers was 5000, the capacity of remanufacturing the goods in all production centers was 4000; the capacity of all distribution centers was 4000; the capacity of distributing used products in all distribution centers was 4000; the capacity of manufacturing the new materials obtained from secondhand products in all supply centers was 3000; the capacity of collection/rehabilitation centers was in the uniform range of [2000,4000]; recycling was in the uniform range of 4000 to 6000; and the capacity of disposal centers was in the uniform range of [2000,4000].
- The cost of establishing disposal centers was in the uniform range of [4000,6000]; the cost of establishing collection/rehabilitation centerswas in the uniform range of [8000,10000]; and recycling centers was in the uniform range of[12000,16000]. In addition, the cost of establishing distribution centers was in the uniform range of[5000,10000].
- The amount of return products from collection centers to other centers was produced randomly in the range of 0 to 1.
- The amount of return products from customers was produced randomly in the uniform range of [0,50].
- All transportation costs wereproduced randomly in the uniform range of [1,1000].
- The costs of maintaining the inventory was considered in the uniform range of[400,600].
- The number of job opportunities created in all centers was produced in the uniform range of[30, 60].
- The produced average waste was considered as 10% of the production rate.
- The produced average dangerous materials were considered as 15% of the production rate.
- The weight factors values of the produced waste, dangerous materials, and damage to workforce was calculated based on the defined mean values for producing the waste and dangerous materials.
- The size of population and number of iteration for both algorithms were respectively 200 and 500. Mutation and crossover rate for implementing NSGA-II algorithms were respectively 0.1 and 0.8.

After adjusting the parameters, the sample problems were solved by the two algorithms and their results were explained below. It should be noted that S/J/

Table 1: Solving small problems

Prob.	PSO			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/2/2/2/2/2/2	79.52	1.34	513.7	20.47	0.79	306.6
1/2/2/2/3/3/3	69.73	1.5	510.5	30.27	1.03	313.4
1/2/2/2/4/4/4	83.41	0.84	542.2	16.59	0.51	329.3
1/2/2/2/5/5/5	100	0.97	539.4	0	0.85	343.2

Table 2: Solving medium problems

Prob.	PSO			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/3/7/7/7/5/4	76.27	1.35	1399.1	23.73	1.03	969.1
2/3/7/7/7/5/4	87.13	0.98	3167.8	12.87	0.73	1931.4
3/3/7/7/7/5/4	88.76	1.11	4596.9	11.24	0.45	1671.7
1/6/8/10/8/6/5	96.99	1.05	1368.3	3.01	0.71	1857.2
2/6/8/10/8/6/5	81.99	0.81	2436.7	18.01	0.84	1643.7
3/6/8/10/8/6/5	75.79	1.25	3857.3	24.21	0.49	2245.7
1/7/9/15/9/7/7	92.11	0.58	4028.1	7.89	0.83	2784.5
2/7/9/15/9/7/7	91.41	0.84	2464.2	8.59	0.77	3740.5
3/7/9/15/9/7/7	100	1.07	7895.4	0	0.69	4540.7

Table 3: Solving big problems

Prob.	PSO			GA		
	Quality metric	Spacing metric	Diversity metric	Quality metric	Spacing metric	Diversity metric
1/10/20/30/16/7/6	100	0.96	7678.9	0	0.52	5739.3
2/10/20/30/16/7/6	81.53	1.12	7945.1	18.47	0.71	5858.5
3/10/20/30/16/7/6	100	1.17	8939.5	0	0.74	6619.7
1/15/40/70/35/12/10	100	1.02	8393.8	0	0.66	6941.2
2/15/40/70/35/12/10	93.11	0.98	9116.3	6.89	0.77	8456.2
3/15/40/70/35/12/10	88.61	0.89	9253.7	11.39	0.54	8564.6
1/15/45/90/40/15/13	85.13	1.24	9894.1	14.87	0.67	9391.2
2/15/45/90/40/15/13	86.37	0.71	10291.6	13.89	0.62	9472.9
3/15/45/90/40/15/13	100	0.97	10749.4	0	0.78	9248.8

K/L/M/P/N symbol was used to display the sample parameters. S is the number of products, J is the number of production centers, K is the number of distribution centers, M is the number of collection centers, P is the number of recycling centers, and N is the number of burial and disposal centers. It should be noted that the number of supply centers for small problems was 1, whilethe numbers for medium and large problems were respectively 2 and 5.

The results obtained from the two algorithms were compared to each other based on the comparative factors of quality, diversity, and uniformity. The comparative results indicated that PSO algorithm has always a higher ability in producing the solutions with higher quality than NSGA-II algorithm. In addition, PSO algorithm can produce the solutions with higher diversity than NSGA-II algorithm. In other words, PSO algorithm has a higher ability in discovering and extracting the feasible area of solution than NSGA-II algorithm. However, NSGA-II algorithmproduces the solutions with higher uniformity than PSO algorithm. Furthermore, the time to implement PSO algorithm is more than NSGA-II algorithm.

CONCLUSION

In this study, a three-objective model for the integrated closed-loop supply chain was studied. In this model, social responsibilities were considered. The objectives considered for the proposed model were minimizing the supply chain costs, maximizing social responsibility or social benefits, and minimizing the environmental effects. PSO algorithm based on Pareto archive was designed to solve the model for small, medium, and big sample problems. In addition, the results of the proposed algorithm were compared to the results of NSGA-II algorithm to study the parameters of the suggested algorithm. The results of problem solving by the above-mentioned algorithms showed that PSO algorithm has a higher ability in achieving the solutions with higher quality and higher diversity than NSGA-II algorithm.

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