Advances in Environmental Technology 1 (2017) 27-43

Advances in Environmental Technology

journal homepage: http://aet.irost.ir

A mathematical multi-objective model for treatment network design (physical-biological-thermal) using modified NSGA II

Masoud Seidi[1*], Mehdi Karimi Rad[2], Saeed Sadeghi[3]

[1] *Faculty of Engineering, University of Ilam, Ilam, Iran*

[2] *University of Tehran, Tehran, Iran*

[3] *Department of Industrial Engineering, Ilam Branch, Islamic Azad University, Ilam, Iran*

ARTICLE INFO

Article history:
Received 29 November 2016
Received in revised form
3 April 2017
Accepted 14 May 2017

Keywords:
Collection center
Modified NSGAII
Network design
Treatment center

DOI: 10.22104/aet.2017.493

ABSTRACT

Today, sustainable development is one of the important issues in regard to the economy of a country. This issue magnifies the necessity for increased scrutiny towards issues such as environmental considerations and product recovery in closed-loop supply chains (CLSCs). The most important motivational factors influencing research on these topics can be considered in two general groups: environment-friendly legal requirements and cost efficiencies. The most important elements in the closed-loop supply chain include collection centers and treatment centers. This paper intended to design a network according to the mentioned principles. In this regard, three types of product treatment centers were taken into account: physical, biological, and thermal. The network design was made via a new mixed multi-objective nonlinear mathematical model of integers. In this model, three objective functions were considered that included profit maximization, pollution minimization, and the minimization of the number of facilities under construction. The model was obtained after determining the number of collection and treatment centers, the number of containers for storage of different waste materials, the amount of waste sent from collection centers to the treatment centers, and the areas covered by collection centers. Due to the conflicting objective functions, a corrected NSGAII algorithm was used to solve this model. The change applied in the mentioned algorithm was made to determine the appropriate amount of the crossover percentage. The improvement in the performance of the proposed solution algorithm is shown using a numerical example. To prove the improved performance, a T-test was used to compare the means between the two populations. To select the optimum answer from the Pareto solution set, indices of D, S, and solution time were used and solved with TOPSIS.

1. Introduction

Traditional logistic managers emphasize the direct or forward flow of materials and products to manage the flow of goods, which is mainly the flow from suppliers to the manufacturers, distributors, retailers, and ultimately consumers. But in many industries, there is another important flow in supply chains which is formed reversely in which the goods will be returned to higher levels from lower levels of the supply chain. Reverse logistic management and CLSCs are two crucial aspects of any business which involves making and distributing services and supporting any type of product. In the current age of ever shorter product life cycles, new governmental and green regulations related to the restoration and removal of electronic waste and other hazardous materials compels the managers of logistics and

*Corresponding author. Tel.: +989188418315
E-mail address: m.seidi@ilam.ac.ir

supply chain processes to focus more attention on the process of CLSC management. In some scientific references, the concepts of closed-loop supply chain management and green supply chain management are often used interchangeably. Albeit, these two concepts differ slightly, CLSC management entails economic aspects as well as social and environmental sustainability; hence, this concept is wider than green supply chain management, and the green supply chain management is in fact part of the CLSC management. There are currently four models of reverse logistics and closed-loop supply chains in the business field:

1. Model of independent reverse logistics.
2. Closed-loop supply chain model in high technologies
3. Closed-loop supply chain model in standard technologies
4. Closed-loop supply chain model in consuming items

By expansion and intensification of the competitive space in today's world, supply chain management has become a critical issue facing economic firms which has affected all operations in organizations regarding production, improved quality, reduced costs, and provision of services needed by customers. On the other hand, with the increase in the volume of greenhouse gases and other pollutants, managers and researchers have sought to design and develop networks which focus on environmental factors and the reduction of pollutants in all sectors as well as emphasizing economic optimization. In recent years, because of the increased speed and volume of communication worldwide and the expansion of competition among manufacturing and service organizations, the importance of optimal design and the application of an optimized economic supply chain is being considered by managers and officials more than ever. One of the most important issues in the strategic planning of the supply chain or network design is the positioning of facilities and assignment of the flow between the selected facilities. In most research, the forward supply chain is studied such that organizations have no responsibility for the products after delivery to the customer. Gradually and with the intensification of a competitive environment, officials and industrialists have inserted reverse flows in supply chain models in order to attract more customers and avoid losing current customers. Today, CLSCs play an undeniable role in industries, such that hundreds of studies have been published in this field. From 1955 to 2005, more than 180 papers were published in the field of closed-loop supply chain and 73,000 businesses in the United States took advantage of the CLSC [1,2]. Closed-loop systems include input, process, structure, and output, all of which are separately evaluated in various studies. However, most of the mathematical models in the field are deterministic and less attention has been paid to the non-deterministic nature of demand and return. One of the challenges in planning for the implementation of a closed loop system is "capacity". When there is a limited capacity, achieving the policy of optimized allocation will become difficult. Meanwhile, the quality and refurbishing time of the returned (defected) products is quite uncertain. According to the above facts, it appears that deeper attention must be devoted to the subject of closed-loop chains. The closed-loop system proposed in this article considers physical, thermal, and biological treatment types. Physical, thermal, and biological treatments include the following:

Physical treatments usually involve the separation of solids from solids, solids from liquids, and liquids from liquids. In rare cases, the separation of gases from solids or liquids might be necessary. Normally, physical treatment entails the lowest cost and is the least complicated treatment process.

Thermal treatment is the destruction of waste materials by oxidation which is used for liquid and solid waste. Thermal treatment is widely used for organic waste, pharmaceutical waste, and pesticides.

Biological treatment entails the use of living organisms to convert waste hazardous materials to non-hazardous and useful materials. Biological treatment is widely used for contaminated soil, water and wastewater, and landfill leachate.

2. Literature Review

In the real world, when both forward and reverse networks are considered together, a closed-loop supply chain is created [1]. Many efforts have been made for modeling and optimizing the supply chain of network design issues which are mainly based on objectives such as minimizing costs or maximizing profits [2]. However, green goals such as lowering greenhouse gas emissions play an undeniably important role in network design issues. For example, Zeballos et al. showed an objective function which minimizes the expected costs (including facilities, purchase, storage, transportation, and emission costs of greenhouse gases) minus the expected revenue from the resale of returned products (collected from repair and decomposition centers) through the forward network [3]. Regarding the need to reduce the use of raw materials, pollution prevention, waste management, social responsibility, and social and environmental issues, RL / CLSC has been significantly considered by researchers. Many efforts have been made to consider certain issues in the field of supply chain network design in RL and CLSC fields [1]. Hatefi and Jolai considered reliability factors for designing a forward / backward integrated logistics network. The proposed model was formulated and solved using the recent robust optimization method for protecting the network against uncertainty. In fact, an MILP model with full constraints was presented to control network reliability among various scenarios [4]. Validi et al. used green approaches in routing of the area. On the other hand and with regard to the approach of this article, various studies can be conducted on multi-objective optimization of the network design supply chain [5]. Subramanian et al. considered a single-period, single product, and multi-layer model and developed it using multi-objective linear integer programming with the use of a simulated annealing algorithm [6]. Soleymani et al. developed a multi-layer, multi-product, and multi-period model in an MILP structure. Their proposed model was solved via CPLEX optimization software and developed through a GA. Their results showed acceptable development of GA [7]. Subramanian et al. provided a dual-purpose network design problem for multi-period, multi-product CLSC to minimize costs and maximize productivity. They provided a dual-purpose MILP model to help construction decisions in the following areas: 1. Operational decisions / layout for warehouses, combination of production facilities; and 2. Production and distribution of products between stages of the supply chain. Garg et al. presented a dual-purpose model in order to show the green closed loop network design. Their model integrates environmental issues and the traditional logistic system [8]. Fallah-Tafti et al. provided a multi-objective model and solved it via a well-known STEP method. Their model has three purposes including cost, rating of the supplier, and the delivery time. Hosni et al. developed a multi-product, multi-period, and multi-layer model on formulating the limited storage life and developed an efficient memetic algorithm for it [9]. Validi et al. considered the total cost, CO_2 emission, and the vehicle distance during transportation. Their optimization model is formulated to make strategic decisions based on an integrated combination of integer programming of zero and one with regard to the green constraints using an AHP formulated approach [10]. Table 1 shows a summary of recent research along with their comparison with the model proposed by this paper.

Table 1. A summary of the literature review

Solution method	Type of the objective function									Objective function	Network	Year	Author
	No. of facilities	Publications	Service efficiency	Delivery time	Ranking of the …	Revenue	Quality	Profit	cost	Multiple	clsc		
Fuzzy				✔			✔	✔		✔	✔	2013	Ramezani et al. [1]
CPLEX									✔		✔	2013	Soleymani et al. [7]
Exact solution						✔			✔	✔	✔	2014	Zeballos et al. [3]
Scenario analysis		✔							✔	✔		2014a	Validi et al. [11]
Hierarchical analysis		✔							✔	✔	✔	2014b	Validi et al. [10]
Non-preemptive goal programming			✔						✔	✔	✔	2014	Subramanian et al. [8]
Exact solution		✔							✔	✔	✔	2014	Garget al. [12]
STEP method				✔	✔				✔	✔	✔	2014	Fallah-Taftiet al. [9]
MOGA-II		✔							✔	✔		2015	Validiet al. [13]
PSO									✔	✔		2016	Keshtzari et al. [14]
NSGA II Corrected	✔	✔						✔	✔		**Proposed model**		

3. The proposed model

In Figure 1, a closed-loop supply chain network is shown. Forward and backward flows are shown in this network. Part of the network that is discussed in this article is specified with a dotted margin. As you can see, the proposed model contains three sections: waste-producing sources, collection and treatment centers (physical, thermal, and biological). In this model, it is assumed that the waste materials also have different varieties.

For this purpose, the following indices were identified:

Waste producing sources

$$i = 1،2، \ldots ،I$$

Waste collection centers

$$j = 1،2، \ldots ،J$$

Types of waste

$$k = 1،2، \ldots ،K$$

Physical treatment centers

$$p = 1،2، \ldots ،P$$

Thermal treatment centers

$$t = 1،2، \ldots ،T$$

Biological treatment centers

$$b = 1.2. \dots .B$$

The model assumes that there are different waste producing sources which generate various types of waste. This produced waste is to be collected by collection centers. The answer to the question as to whether collection centers will be built in different locations or not is given by the model. In other words, the model also specifies the number of these centers and then determines the collection center covering each waste producing source. In collection centers, there are containers for keeping waste materials whose number is determined by the proposed model. Finally, the model determines which treatment centers these waste materials will be sent to and also defines their volumes. The required parameters are thus defined as below:

a Rate or percentage of the parts which go to the physical treatment

b Rate or percentage of the parts which go into the thermal treatment center

c Rate or percentage of the parts which go into the biological treatment center

EC_{kij} The amount of carbon emissions per transport of each unit of k-type material from the i^{th} producing source to the j^{th} collection center

EAP_{kjp} The amount of carbon emissions per transport of each unit of k-type material from the j^{th} collection source to the p^{th} physical treatment center

EAT_{kjt} The amount of carbon emissions per transport of each unit of k-type material from the j^{th} collection center to the t^{th} thermal treatment center

EAB_{kjb} The amount of carbon emissions per transport of each unit of k-type material from the j^{th} collection center to the b^{th} thermal treatment center

EP_{kp} The amount of carbon emissions per physical treatment operations of each unit of k-type material at the center of p-th physical treatment center

ET_{kt} The amount of carbon emissions per thermal treatment operations of each unit of k-type material at t-th thermal treatment center

EB_{kb} The amount of carbon emissions per biological treatment operations of each unit of k-type material at b-th biological treatment center

CW_p Fixed cost of the p-th physical treatment center

CM_t Fixed cost of the t-th thermal treatment center

CN_b Fixed cost of the b-th biological treatment center

g_{jp} Is the coating parameter and its value is equal to 1 when the distance between the p-th physical treatment center and the j-th collection center is less than the radius of coverage; otherwise it is equal to zero

h_{jt} Is the coating parameter and its value is equal to 1 when the distance between the t-th thermal treatment center and the j-th collection center is less than the radius of coverage; otherwise it is equal to zero

l_{jb} Is the coating parameter and its value is equal to 1 when the distance between the b-th biological treatment center and the j-th collection center is less than the radius of coverage, otherwise it is equal to zero

q_{kij} Daily production of waste material type-k by the i-th producing source of waste materials given to the j-th collection center

b_k Capacity of the container keeping k-type waste material

P_{kp} Capacity of the p-th physical treatment center for operation on the waste material type k

T_{kt} Capacity of the t-th thermal treatment center for operation on the waste material type k

B_{kb} Capacity of the b-th biological treatment center for operation on the waste material type k

Nb_{kj} Total number of containers for storing k-type waste material in j-th collection center

CT_{kjp} Transportation cost of the waste material type k from the j-th collection center to the p-th physical treatment center

CT_{kjt} Transportation cost of waste material type k from the j-th collection center to the t-th thermal treatment center

CT_{kjb} Transportation cost of waste material type k from the j-th collection center to the b-th biological treatment center

BP_k Profit gained from the physical treatment of waste material type k

BT_k Profit gained from the thermal treatment of waste material type k

BB_k Profit gained from the biological treatment of waste material type k

CC_j Construction cost of the j^{th} collection center

CA_{ij} Costs for allocation of the i^{th} source producing waste material to the j^{th} collection center

CK_{kj} Costs for purchase of the container for keeping waste material type k in the j^{th} collection center

CP_{kp} Costs for physical treatment of the waste material type k in the p^{th} physical treatment center

CT_{kt} Costs for thermal treatment of the waste material type k in the t^{th} thermal treatment center

CB_{kb} Costs for biological treatment of the waste material type k in the b^{th} biological treatment center

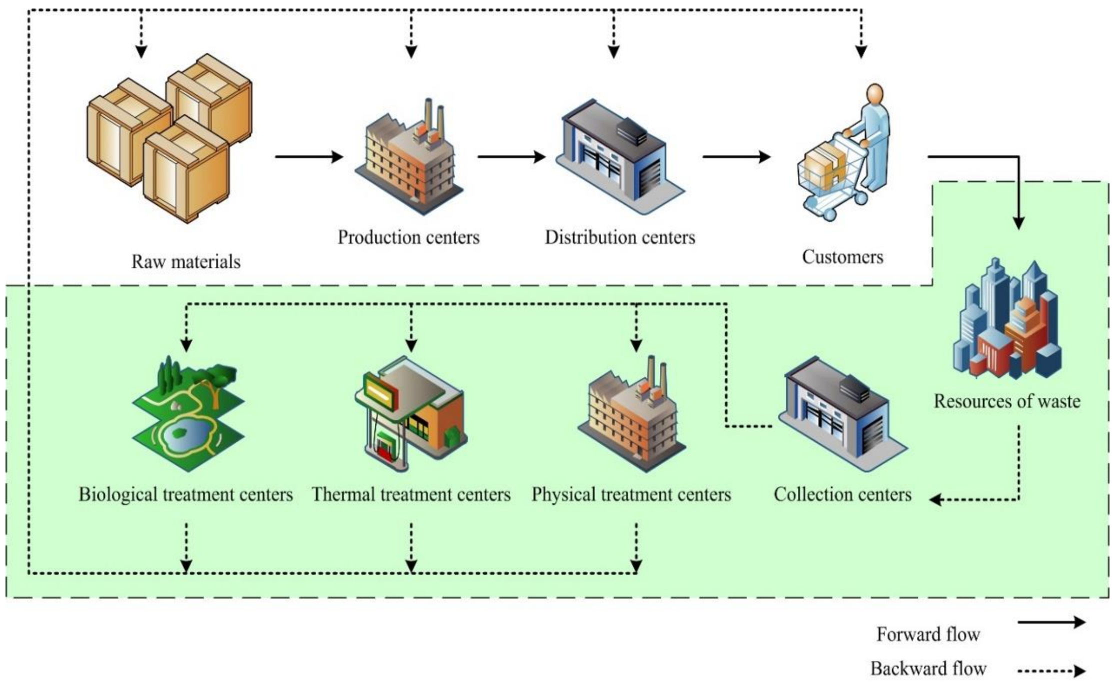

Fig 1. Closed-loop supply chain network

3.1. Decision variables are defined as follows

z_j is equal to one if built in the j[th] region of the collection center, otherwise zero

x_{ij} is equal to one if the source producing the i[th] waste material is covered by the j[th] collection center, otherwise zero

y_{kj} number of containers for keeping waste material type k in the j[th] collection center (integer)

APT_{kjp} the amount of waste material type k transported from the j[th] collection center to the p[th] physical treatment center

ATT_{kjt} the amount of waste material type k transported from the j[th] collection center to the t[th] thermal treatment center

ABT_{kjb} the amount of waste material type k transported from the j[th] collection center to the b[th] biological treatment center

W_p is equal to one if the p[th] physical treatment center is built, otherwise zero

M_t is equal to one if the t[th] thermal treatment center is built, otherwise zero

N_b is equal to one if the b[th] biological treatment center is built, otherwise zero

Three objective functions are considered in the model which are addressed in this section. The first objective function is profit maximization. The second objective function is defined as minimization of carbon emissions and pollution; the third objective function is the minimization of the number of construction facilities for coverage by related centers:

$$\begin{aligned}\mathrm{Max\,I} = {} & \sum_{k=1}^{K} BP_k\left(\sum_{j=1}^{J}\sum_{p=1}^{P} APT_{kjp}\right) + \sum_{k=1}^{K} BT_k\left(\sum_{j=1}^{J}\sum_{t=1}^{T} ATT_{kjt}\right) + \sum_{k=1}^{K} BB_k\left(\sum_{j=1}^{J}\sum_{b=1}^{B} ABT_{kjb}\right) - \\ & \Big(\sum_{j=1}^{J} CC_j Z_j + \sum_{p=1}^{P} CW_p W_p + \sum_{t=1}^{T} CM_t M_t + \sum_{b=1}^{B} CN_b N_b + \sum_{i=1}^{I}\sum_{j=1}^{J} CA_{ij} x_{ij} + \\ & \sum_{k=1}^{I}\sum_{j=1}^{J}\sum_{p=1}^{P} CT_{kjp} APT_{kjp} + \sum_{k=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} CT_{kjt} ATT_{kjt} + \sum_{k=1}^{I}\sum_{j=1}^{J}\sum_{b=1}^{B} CT_{kjb} ABT_{kjb} + \sum_{k=1}^{K}\sum_{j=1}^{J} CK_{kj} y_{kj} + \\ & \sum_{k=1}^{K}\sum_{p=1}^{P} CP_{kp}\left(\sum_{j=1}^{J} APT_{kjp}\right) + \sum_{k=1}^{K}\sum_{t=1}^{T} CT_{kt}\left(\sum_{j=1}^{J} ATT_{kjt}\right) + \sum_{k=1}^{K}\sum_{b=1}^{B} CB_{kb}\left(\sum_{j=1}^{J} ABT_{kjb}\right)\Big)\end{aligned} \quad (1)$$

$$\begin{aligned}\mathrm{MinII} = {} & \sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{j=1}^{J} EC_{kij} q_{kij} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{p=1}^{P}\left(EAP_{kjp} + EP_{kp}\right) APT_{kjp} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{t=1}^{T}\left(EAT_{kjt} + \right. \\ & \left. ET_{kt}\right) ATT_{kjt} \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{b=1}^{B}\left(EAB_{kjb} + EB_{kb}\right) ABT_{kjb}\end{aligned} \quad (2)$$

$$\mathrm{MinIII} = \sum_{j=1}^{J} Z_j + \sum_{p=1}^{P} W_p + \sum_{t=1}^{T} M_t + \sum_{b=1}^{B} N_b \quad (3)$$

The weight of the objective functions are equal. All weights are equal to one (W_1=W_2=W_3=1).

Model constraints are defined as follows: Constraint 1: In this constraint, each source producing waste material is allowed to be covered by only one collection center.

$$\sum_{j=1}^{J} x_{ij} Z_j = 1 \quad \forall\, i \in \{1, \dots J\} \quad (4)$$

Constraint 2: The values of each type of collected waste materials in each collection center shall not exceed the capacity of its storage containers.

$$\sum_{i=1}^{I} q_{ki} x_{ij} \le b_k y_{kj} Z_j \quad \forall\, j \in \{1, \dots J\}, k \in \{1, \dots K\} \quad (5)$$

Constraint 3: The number of the waste storage containers in each center shall not be more than a specified number.

$$y_{kj} \le Nb_{kj} Z_j \qquad \forall\, k \in \{1,\dots,K\}, j \in \{1,\dots,J\} \tag{6}$$

Constraint 4: The amount of the waste materials sent to the physical treatment centers shall not exceed their capacity.

$$\sum_{j=1}^{J} APT_{kjp} \le P_{kp} W_p \qquad \forall\, k \in \{1,\dots,K\}, p \in \{1,\dots,P\} \tag{7}$$

Constraint 5: The amount of the waste materials sent to the thermal treatment centers shall not exceed their capacity.

$$\sum_{j=1}^{J} ATT_{kjt} \le T_{kt} M_t \qquad \forall\, k \in \{1,\dots,K\}, t \in \{1,\dots,T\} \tag{8}$$

Constraint 6: The amount of the waste material sent to biological treatment centers shall not exceed their capacity.

$$\sum_{j=1}^{J} ABT_{kjb} \le B_{kb} N_b \qquad \forall\, k \in \{1,\dots,K\}, b \in \{1,\dots,B\} \tag{9}$$

Constraint 7: All waste materials shall be sent to the treatment centers.

$$\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{p=1}^{P} APT_{kjp} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{t=1}^{T} ATT_{kjt} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{b=1}^{B} ABT_{kjb} = \sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{j=1}^{J} q_{kij}\, x_{ij} \tag{10}$$

Constraints 8 to 10: The following constraints ensure that the total flows going to the treatment centers are a percentage or proportion of the total flows accumulated in collection centers from waste production centers.

$$\sum_{p=1}^{P} APT_{kjb} = a \sum_{i=1}^{I} q_{kij} \qquad \forall k,j \tag{11}$$

$$\sum_{t=1}^{T} ATT_{kjt} = b \sum_{i=1}^{I} q_{kij} \qquad \forall k,j \tag{12}$$

$$\sum_{b=1}^{B} ABT_{kjb} = c \sum_{i=1}^{I} q_{kij} \qquad \forall k,j \tag{13}$$

Constraint 11: The funding restriction for construction of the treatment centers is defined as follows:

$$\sum_{p=1}^{P} CW_p W_p + \sum_{t=1}^{T} CM_t M_t + \sum_{b=1}^{B} CN_b N_b \le BD \tag{14}$$

Constraints 12 to 14: The following constraints guarantee that the collection centers are covered by the treatment centers with regard to the radius of the intended coverage.

$$\sum_{p=1}^{P} g_{jp} W_p \ge 1 \qquad \forall j \tag{15}$$

$$\sum_{t=1}^{T} h_{jt} M_t \ge 1 \qquad \forall j \tag{16}$$

$$\sum_{b=1}^{B} l_{jb} N_b \ge 1 \qquad \forall j \tag{17}$$

4. Genetic algorithm based on non-dominant ranking

Evolutionary algorithms are popular approaches to generating Pareto optimal solutions to a multi-objective optimization problem. Currently, most evolutionary multi-objective optimization algorithms apply Pareto-based ranking schemes. Evolutionary algorithms such as the Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) have become standard approach. NSGAII is one of the most versatile and powerful algorithm for solving multi-objective optimization. Its efficiency in solving various problems has been proven. NSGA-II is the second version of the famous "Non-dominated Sorting Genetic Algorithm" based on the work of Prof. Kalyanmoy Deb for solving non-convex and non-smooth single and multi-objective optimization problems. Its main features are:

1. A sorting non-dominated procedure where all the individual is sorted according to the level of non-domination;
2. It implements elitism which stores all non-dominated solutions, and hence enhancing convergence properties;
3. It adapts suitable automatic mechanics based on the crowding distance in order to guarantee diversity and spread of solutions;
4. Constraints are implemented using a modified definition of dominance without the use of penalty functions.

In this article, we have tried to change the crossover percent and population during the execution of the algorithm. This change improves the performance of the algorithm .The steps of the proposed algorithm are as follows:

Step 1: The generation of the initial population in this method is normally based on the scale and constraints of the problem and definition of input parameters.

$$d_{ij} = \sqrt{\sum_{i=1}^{M} \left(\frac{f_i(x) - \bar{z}_i}{f_i^{max} - f_i^{min}}\right)^2} \tag{18}$$

Step 2: The evaluation of the generated population from the perspective of defined target functions.

Step 3: The application of the non-dominated arrangement members of the population fall into categories such that members in the first category are not dominated by other members of the current population. On the same basis, members in the second category are dominated by the members of the first category; this trend continues in the same way in other categories such that a rank is assigned to all members in each category based on the category number.

Step 4: Calculating the control parameter called the population distance. This parameter is calculated for each member in all groups and represents the sample nearness to the other members of that group. The great value of this parameter leads to the divergence and better range of the population

Before calculating the population distance, the following steps should be taken:

Step 4.1: The normalized Euclidean distance of each answer in the non-dominated queue is calculated from any reference point (based on Equation 18) and the answers are arranged by the distance from each reference point in ascending order. Hence, the closest answer to the reference point is ranked as one.

Where

f_i^{max}: Maximum value of the ith objective function

f_i^{min}: Minimum value of the ith objective function

$\bar{z}_i$: Reference point of the objective function

M: The number of objective functions

Step 4.2**:** When the first stage calculations were performed for all reference points, the lowest rank dedicated to an answer is considered as its priority distance. In this way, the closest answers to the reference points take the lowest priority distance, i.e., one and so on. Solutions with smaller priority distance are preferred in contests and formation of the new population from the mixed population of parents and children.

Step 4.3: To increase the variety of the obtained answers, the idea of clearing Epsilon is used in the positioning operator. First, an answer is chosen randomly from the non-dominated set. Then, the priority distance of all answers, whose total normalized difference value in their objective functions (calculated from equation 19) is less than the Epsilon selected answer, is modified such that a large synthetic value is assigned to the priority distance calculated in the previous step of these answers such that they do not win the contest. Hence, only one answer in the neighborhood Epsilon is emphasized. Then, another answer (which has not been previously considered) is randomly selected from the non-dominated set and the above procedure is repeated and it continues until all the answers of the non-dominated queue are considered.

Step 5: Selecting the parent population for breeding one of the selection mechanisms based on dual tournament between the two members randomly selected from the population.

Step 6: Repeat the above six steps j_{max} times.

Step 7: Calculate the following three indicators (MID, D and S):

MID index: The criteria by which we measure the nearness to the real Pareto optimal level is calculated from equation 20 and 21:

$$\mathrm{MID} = \frac{\sum_{i=1}^{n} c_i}{n} \tag{20}$$

where n is the number of Pareto solutions and c_i is the Euclidean distance of each member of the Pareto set from the ideal point which is calculated from the following equation:

$$C_i = \sqrt{(f_{1i} - f_1^*)^2 + (f_{2i} - f_2^*)^2 + \cdots + (f_{mi} - f_m^*)^2} \tag{21}$$

where f_{mi}: is the value of mth function in the ith solution. The lower the value of ci, the better the answer set.

S index: The index measures the relative distance of successive answers or density:

$$S = \sqrt{\frac{1}{|Q|}\sum_{i=1}^{|Q|}(d_i - \bar{d})^2} \tag{22}$$

$$d_i = \min_{k\in Q \wedge k\neq i} \sum_{m=1}^{M} |f_m^i - f_m^k| \tag{23}$$

$$\bar{d} = \sum_{i=1}^{|Q|} \frac{d_i}{|Q|} \tag{24}$$

In the above passages, | Q | indicates the number of Pareto solutions. The lower the above of this index, the better the solution set.

D index: This scale measures the diagonal length of the space cube built by the end values of the non-dominated set of answers in the target space. The greater value of this scale represents further expansion of the Pareto archived solutions calculated as below:

$$D = \sqrt{\sum_{m=1}^{M}(\max_{i=1:|Q|} f_m^i - \min_{i=1:|Q|} f_m^i)^2} \tag{25}$$

Step 8: Correcting the crossover percentage using the distancing index as follows:

$$\alpha_i = \alpha_i \times \frac{1}{S} \tag{26}$$

Accordingly, the crossover percentage leading to a lower distancing index is more likely to be selected. See Figure 2.

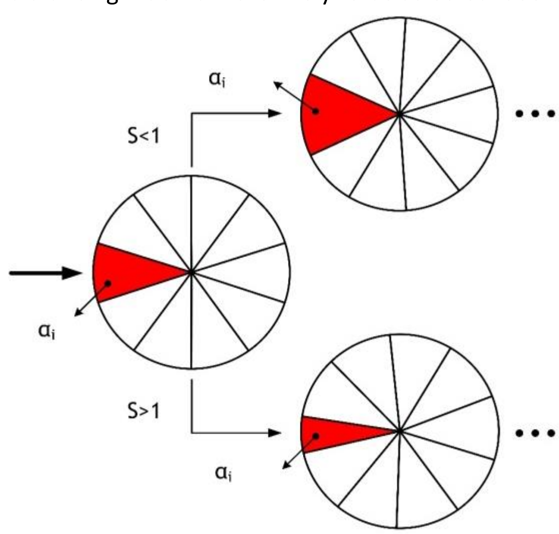

Fig. 2. Correction of the crossover percentage

Step 9: We repeat the nine above steps k_{max} times.

It should be noted that in order to determine the reference points, the model was solved by weighting the target functions. The above proposed procedure is shown in Figure 3.

5. Numerical analysis

For a more detailed analysis of the proposed approach, a problem with the following dimensions was used in this section of the article:

i : Waste producing sources; i=1, 2,
j : Waste collection centers; j=1, 2, 3
k : Types of waste: k=1, 2, 3, 4
p : Physical treatment centers; p=1, 2, 3, 4, 5
t : Thermal treatment centers; t= 1, 2, 3, 4, 5, 6
b : Biological treatment centers; b= 1, 2, 3, 4, 5, 6, 7
Problem parameters are given in Tables 2 to 6.

The above problem was coded using the proposed approach, *i.e.*, NSGAII with the correction of the crossover percentage and simple NSGAII in Matlab software. The results are shown in Table 7 for n_i and j_{max}. It is worth noting that the numbers listed in each table are coded for an average of 20 times for execution of coding programs. As can be seen, the two methods are exactly equal in the MID index and the T-test was used in both S and D indexes to compare the means whose results are presented in Tables 8 and 9. This means that the value of D in the proposed NSGAII method in two MID and D indexes acts the same as the simple NSGAII and the proposed NSGAII index has led to improvement in S index. The average 20-time implementation of the proposed NSGAII is shown in more detail in Table 10.

Table 2. Problem parameters

EB_{kb}		B						
		1	2	3	4	5	6	7
k	1	92	73	88	86	94	23	55
	2	62	71	97	93	51	13	44
	3	95	97	64	59	100	35	77
	4	64	32	63	89	44	98	43

EAB_{kjb}		b=1			b=2			b=3		
	J	1	2	3	1	2	3	1	2	3
k	1	65	60	60	43	50	36	45	48	17
	2	70	93	32	47	76	77	72	95	42
	3	22	40	97	14	85	99	99	35	43
	4	32	89	61	90	76	42	78	66	36

EAB_{kjb}		b=4			b=5			b=6		
	J	1	2	3	1	2	3	1	2	3
k	1	65	91	57	71	50	11	19	60	56
	2	45	22	27	69	26	49	79	10	13
	3	89	95	93	71	78	39	24	96	16
	4	54	37	69	38	98	78	55	41	51

EAB_{kjb}		b=7		
	J	1	2	3
k	1	94	84	28
	2	48	32	49
	3	20	78	88
	4	77	22	29

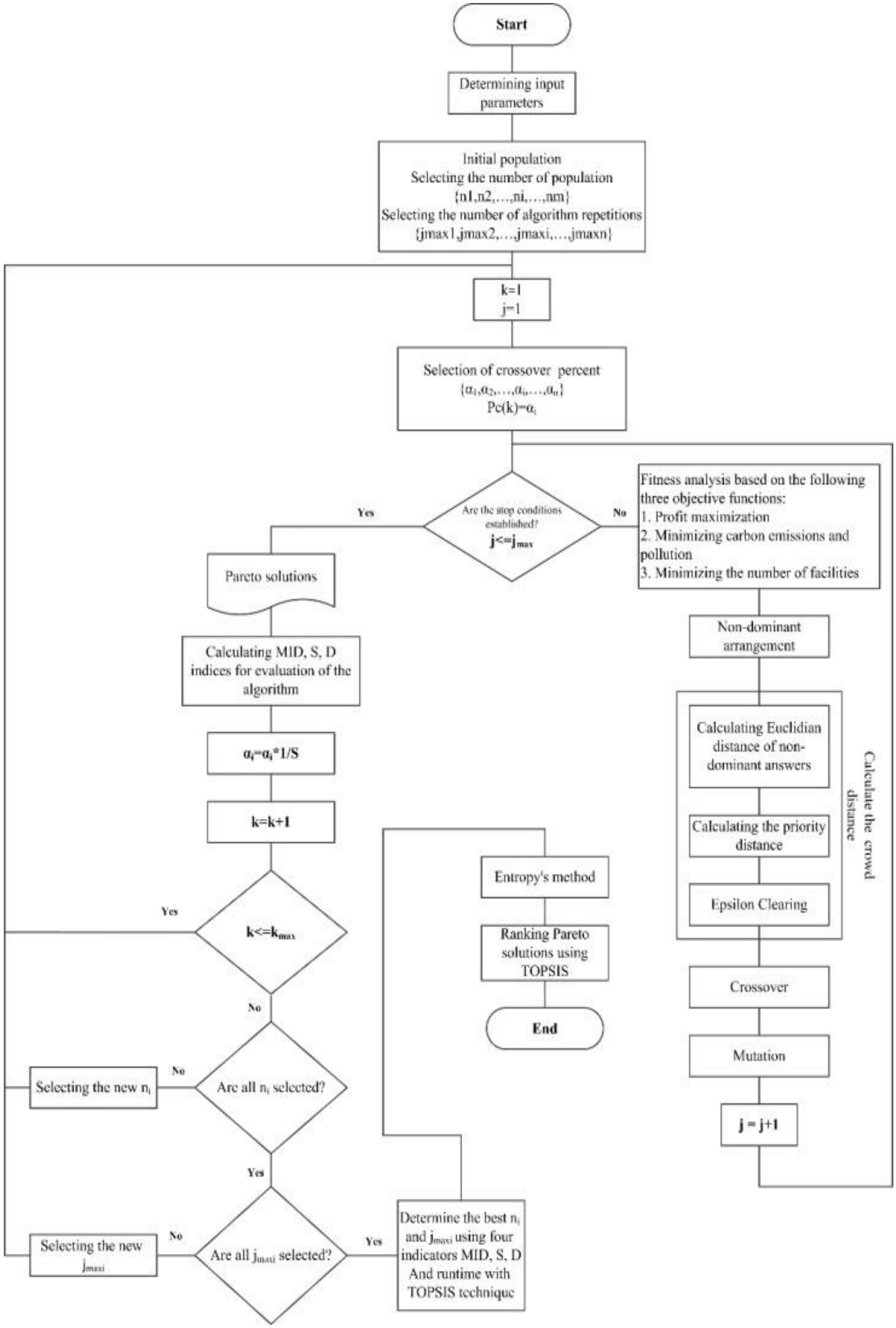

Fig 3. The proposed solution approach

Table 3. Problem parameters

P	1	2	3	4	5
CW_p	78	12	30	84	54

EP_{kp}		P				
		1	2	3	4	5
k	1	22	91	80	49	64
	2	54	26	77	34	38
	3	54	74	91	44	61
	4	60	17	27	53	10

ET_{kt}		T					
		1	2	3	4	5	6
k	1	28	83	84	60	93	65
	2	58	31	75	92	57	44
	3	98	37	25	87	83	16
	4	15	85	95	30	71	19

EAT_{kjt}		t=1			t=2			t=3		
	j	1	2	3	1	2	3	1	2	3
k	1	41	27	97	54	14	62	27	36	17
	2	76	40	45	39	72	52	38	24	12
	3	78	71	46	81	86	75	40	64	20
	4	42	83	47	76	63	80	92	73	96

EAT_{kjt}		t=4			t=5			t=6		
	j	1	2	3	1	2	3	1	2	3
k	1	80	39	48	32	87	63	38	30	22
	2	43	10	75	45	80	87	15	76	35
	3	42	17	16	37	44	72	19	20	13
	4	59	16	40	86	15	52	28	62	98

Table 4. Problem parameters

Nb_{kj}	J		
k	1	2	3
1	593	756	539
2	828	791	230
3	742	361	128
4	156	926	866

Table 5. Problem parameters

EAP_{kjp}		p=1			p=2			p=3		
	j	1	2	3	1	2	3	1	2	3
K	1	65	17	40	59	55	63	15	25	68
	2	11	63	28	80	83	90	86	67	91
	3	33	41	88	40	66	17	99	51	97
	4	80	62	38	24	62	63	83	18	82

EAP_{kjt}		p=4			p=5		
	j	1	2	3	1	2	3
K	1	23	31	13	15	62	58
	2	28	52	78	84	43	11
	3	40	51	68	35	97	16
	4	65	22	21	29	87	97

T	1	2	3	4	5	6
CM_t	58	24	79	45	59	88

k	1	2	3	4
BP_k	65	86	44	77
BT_k	69	37	22	97
BB_k	69	50	86	59

j	1	2	3
CCj	83	14	55

CA_{ij}		j		
		1	2	3
i	1	32	53	77
	2	50	52	75

g_{jp}		p				
		1	2	3	4	5
J	1	17	64	92	11	39
	2	89	92	38	12	84
	3	56	54	48	88	75

h_{jt}		t					
		1	2	3	4	5	6
J	1	40	54	17	54	40	11
	2	62	72	20	39	61	89
	3	78	80	77	61	48	46

B	1	2	3	4	5	6	7
C_{Nb}	53	80	56	96	62	94	72

Table 6. Problem parameters

P_{kp}		P				
		1	2	3	4	5
K	1	25454	13711	20270	27873	20028
	2	15397	17317	13476	14860	22897
	3	13241	26419	2104	15645	27883
	4	17803	19525	15389	24198	24124

B_{kb}		B						
		1	2	3	4	5	6	7
K	1	29809	28828	18159	14171	26918	29250	10505
	2	27587	24231	20885	26575	22305	18388	19793
	3	17440	20027	29090	26451	28937	23491	18537
	4	18098	14266	26781	26240	16842	22074	25313

q_{kij}		j=1		j=2		j=3	
	i	1	2	1	2	1	2
K	1	2999	1349	3215	1097	3076	3910
	2	6078	4057	8609	2130	5845	5336
	3	4537	8369	3320	5741	6267	2996
	4	5235	7932	4774	2404	8492	7718

A	B	C
0.3	0.5	0.2

K	1	2	3	4
b_k	925	262	162	606

T_{kt}		T					
		1	2	3	4	5	6
K	1	12935	22029	25912	25464	19477	16848
	2	18491	23959	28679	26658	15450	24959
	3	26701	28768	26406	27135	28626	23413
	4	20680	17119	17577	16011	22636	28254

Table 7. The average of 20-time executions of the two methods of simple NSGAII and the proposed NSGAII

		NSGAII Simple			NSGAII Proposed		
n_i	j_{max}	MID	S	D	MID	S	D
5	50	1	1.2625	2154.50	1	0.9584	1446.3
5	100	1	1.8854	2023.20	1	0.56926	898.01
5	200	1	1.3003	2095.60	1	0.23104	1891
5	300	1	0.87035	176.55	1	0.34138	1809.6
5	1000	1	1.2816	1921.80	1	0.0059932	1472.2
10	50	1	1.3148	2654.50	1	0.54876	1981.7
15	50	1	0.79686	4753.70	1	0.38103	3181.3
20	50	1	1.1292	3986.50	1	0.67112	5413
25	50	1	0.68122	4865.70	1	0.56357	3707.8
10	100	1	0.7951	2346.00	1	0.4022	1258.8
15	100	1	1.0094	2819.10	1	0.5019	3751
20	100	1	0.83469	4175.20	1	0.61409	3481.3
25	100	1	0.79717	4159.80	1	0.67826	4702.4
10	200	1	0.97775	2805.40	1	0.59274	1750.9
15	200	1	1.3826	2692.40	1	0.7592	2731.4
20	200	1	0.89435	3849.30	1	0.89599	2548.2
25	200	1	0.61177	5667.10	1	0.83689	4162.4
10	300	1	1.0878	1400.30	1	0.3024	1966
15	300	1	1.1946	2262.30	1	0.28284	3822.5
20	300	1	0.72022	2158.80	1	0.58332	4628.1
25	300	1	0.82432	2755.00	1	0.82594	3722.2
10	1000	1	0.75997	2373.10	1	0.6079	2776.2
15	1000	1	1.1916	3118.60	1	0.55776	2723.2
20	1000	1	0.97266	4524.00	1	0.8453	3233.5
25	1000	1	0.8247	4420.70	1	0.50194	3974.4

The above problem was coded using the proposed approach, *i.e.*, NSGAII with the correction of the crossover percentage and simple NSGAII in Matlab software. The results are shown in Table 7 for n_i and j_{max}. It is worth noting that the numbers listed in each table are coded for an average of 20 times for execution of coding programs. As can be seen, the two methods are exactly equal in the MID index and the T-test was used in both S and D indexes to compare the means whose results are presented in Tables 8 and 9.

Table 8. Two-sample T for S_1 vs D

	N	Mean	StDev	SE Mean	
S1	25	1.016	0.288	0.058	
S2	25	0.562	0.228	0.046	
Difference = mu (S1) - mu (S2)					
Estimate for difference:		0.4537			
95% upper bound for difference:		0.5770			
T-Test of difference	T-Value	P-Value	DF	H_0:	H_1:
0	6.18	1.000	45	$S_1 > S_2$	$S_1 \leq S_2$

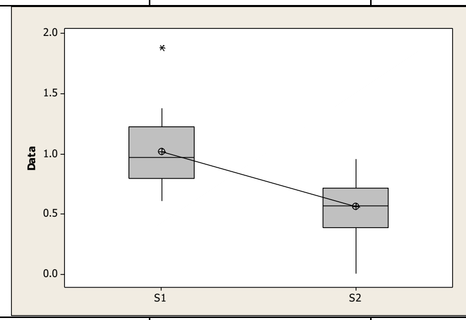

Table 9. Two-sample T for D_1 vs D

	N	Mean	StDev	SE Mean	
D1	25	3046	1275	255	
D2	25	2921	1208	242	
Difference = mu (D_1) - mu (D_2)					
Estimate for difference:		125			
95% CI for difference:		(-581; 832)			
T-Test of difference	T-Value	P-Value	DF	H_0:	H_1:
0	0.36	0.723	47	$D_1 = D_2$	$D_1 \neq D_2$

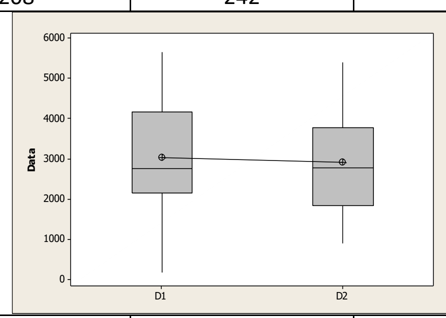

Table 10. The average results of 20-time implementation of two proposed NSGAIIs

n_i	j_{max}	MID	S	D	Min f_1	Max f_1	Min f_2	Max f_2	Min f_3	Max f_3	time
5	50	1	0.9584	1446.3	2.7095008403e-07	3.8110662388e-07	2014599.4	2601519.3	25	25	1.705841
5	100	1	0.56926	898.01	3.2505238544e-07	3.6871509904e-07	2449558	2749694.1	24	25	3.080099
5	200	1	0.23104	1891	4.2042443781e-07	6.5211400361e-07	1678128.2	2752950.8	24	25	6.281555
5	300	1	0.34138	1809.6	4.6099098864e-07	5.7756641927e-07	1568851	2397739	24	25	9.188378
5	1000	1	0.0059932	1472.2	4.5658166349e-07	5.5634711387e-07	1578158.9	2228802.7	24	25	30.007030
10	50	1	0.54876	1981.7	3.1987072105e-07	4.0978934287e-07	1975493.1	2789885.8	24	25	2.398513
15	50	1	0.38103	3181.3	3.6131772865e-07	5.0425119051e-07	2014595.2	2944500.8	24	25	4.103819
20	50	1	0.67112	5413	3.5840991299e-07	7.7818135127e-07	1211355.6	3212785.4	24	26	5.890111
25	50	1	0.56357	3707.8	2.9329094614e-07	3.7871230847e-07	1796271.6	2705394.8	24	26	8.042382
10	100	1	0.4022	1258.8	3.9790715163e-07	4.8453617339e-07	1813434.4	2189957.5	24	26	5.654703
15	100	1	0.5019	3751	3.9353325689e-07	6.2700060217e-07	1577726.8	2909826.3	24	26	9.287908
20	100	1	0.61409	3481.3	4.5318727289e-07	5.7389807123e-07	1423402.2	2608011.7	24	26	11.649198
25	100	1	0.67826	4702.4	3.8355704746e-07	5.2350339149e-07	1700987.3	2895248.6	24	26	15.012792
10	200	1	0.59274	1750.9	3.9670424461e-07	4.8752606071e-07	2075025.2	2622092.8	24	25	9.694530
15	200	1	0.7592	2731.4	3.0717480793e-07	4.2804448136e-07	1924724.2	3058317	24	26	16.371358
20	200	1	0.89599	2548.2	3.398414789e-07	3.9267073785e-07	1716974.7	2584513.8	24	26	21.022432
25	200	1	0.83689	4162.4	3.4352948306e-07	4.4968072668e-07	1713416	3379679.5	24	26	26.888233
10	300	1	0.3024	1966	3.2908081935e-07	5.685652767e-07	1272199.3	2755668.1	24	25	13.567012
15	300	1	0.28284	3822.5	2.5108607911e-07	3.0787410498e-07	1706476.9	3191549.8	24	26	24.177890
20	300	1	0.58332	4628.1	3.2153364862e-07	4.3740309061e-07	1721573.5	3259099.2	24	26	35.794039
25	300	1	0.82594	3722.2	5.9504265206e-07	8.4331096704e-07	1699147.2	2695192.9	24	24	43.709583
10	1000	1	0.6079	2776.2	2.7924647461e-07	3.5667568842e-07	1490089.2	2590560	24	26	56.830176
15	1000	1	0.55776	2723.2	3.2715580298e-07	3.6007706081e-07	1407043.1	2304010.5	24	26	86.027621
20	1000	1	0.8453	3233.5	3.2068123983e-07	4.970962619e-07	1221211.2	2283773.4	24	26	99.323533
25	1000	1	0.50194	3974.4	3.363387895e-07	6.1560517251e-07	855904.5	1991203.6	24	26	135.635327

In this paper, the TOPSIS technique was used to select the best Pareto answer set. The used indicators aimed to assess three indices: S, D and runtime. S and runtime indices are indicators with a negative aspect (the less, the more favorable) and D is the index with a positive aspect (the more, the better). Columns 3, 4, and 11 of the table are considered as the decision matrixes. Before performing the TOPSIS method steps, weights of the three indicators can be obtained as follows using the entropy method:

Step 1: Calculate P_{ij}:

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \qquad ; \forall j \tag{27}$$

P matrix is shown in Table 11.

Table 11. Matrix P

S	D	time (sec)
0.06816877		0.00250364
0.04049015	0.01980327	0.00452062
0.01643334	0.01229588	0.00921936
0.02428157	0.02589226	0.01348567
0.00042628	0.0247777	0.04404094
0.03903203	0.0201579	0.00352027
0.02710178	0.02713416	0.00602312
0.04773521	0.04355952	0.00864484
0.04008543	0.07411676	0.0118037
0.02860755	0.05076855	0.00829934
0.03569899	0.01723595	0.01363174
0.0436788	0.05136006	0.01709738
0.04824306	0.04766723	0.02203408
0.04216022	0.06438697	0.01422854
0.05400014	0.02397396	0.02402803
0.06372969	0.03739932	0.03085436
0.05952605	0.03489088	0.03946352
0.02150901	0.05699309	0.01991213
0.02011775	0.02691919	0.03548558
0.0414902	0.05233906	0.05253445
0.0587472	0.06336963	0.064152
0.04323852	0.05096572	0.08340893
0.03967218	0.03801274	0.12626164
0.06012423	0.03728704	0.14577588
0.03570183	0.04427426	0.19907024

Step 2. Calculate E_j values

$$E_j = -k \sum_{i=1}^{m} \left[P_{ij} ln P_{ij}\right] \qquad ; \forall j ، k = \frac{1}{ln(m)} \tag{28}$$

Step 3. Calculate d_j values

$$d_j = 1 - E_j \qquad ; \forall j \tag{29}$$

Step 4. Calculate w_j weights

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \qquad ; \forall j \tag{30}$$

The calculations of steps 2, 3, and 4 are shown in Table 12.

Table 12. Values of Ej, dj and Wj

E_j	0.969992285	0.973531966	0.825514981
d_j	0.030007715	0.026468034	0.174485019
W_j	0.129925594	0.114599696	0.755474709

Weight of the indicator are: W_S=0.129925594, W_D=0.114599696, and W_{time}=0.755474709.

After calculating the index weights using the TOPSIS technique, we selected the best Pareto solution set. The TOPSIS technique steps are as follows:

Step 1: Quantification and descaling the decision matrix (N): A decision matrix is the one whose rows and columns are respectively dedicated to the items and indices. Descaling is done using software. In this type of descaling, each decision matrix element is divided by the quadrate of the sum of squares of elements in each column.

Step 2: Obtaining the weighted descaled matrix (V): Descaled matrix is multiplied in the diagonal matrix of the weights of indexes $(V = N \times W_{n\times n})$. The calculations of Steps 1 and 2 are included in Table 13.

Step 3: Determine the ideal positive and negative solutions (PIS and NIS).

Positive ideal solution (V_j^+):

[vector of the best values of each matrix index]

Negative ideal solution (V_j^-):

[vector of the worst values of each matrix index]

The ideal positive and negative solutions are displayed in Table 14.

Step 4: Obtain the distance of each item with positive and negative ideals:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \quad ; \ i = 1,2,\dots, m \tag{31}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \quad ; \ i = 1,2,\dots, m \tag{31}$$

Step 5: Determine the relative closeness of CL_i of each item to the ideal solutions:

$$CL_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{32}$$

Table 13. Descaled as well as weighted descaled matrices

descaled matrices				weighted descaled matrices		
S	D	time(sec)		S	D	time(sec)
0.31684427	0.0917719	0.007951984		0.04116618	0.01051703	0.00600752
0.18819571	0.0569813	0.014358254		0.02445144	0.00653004	0.0108473
0.07638116	0.1199893	0.029282228		0.00992387	0.01375074	0.02212198
0.11285924	0.1148243	0.042832735		0.0146633	0.01315883	0.03235905
0.00198133	0.0934153	0.139881398		0.00025743	0.01070536	0.10567686
0.18141847	0.1257445	0.011180958		0.0235709	0.01441028	0.00844693
0.12596742	0.2018626	0.019130448		0.01636639	0.02313339	0.01445257
0.22187033	0.3434703	0.027457465		0.02882663	0.03936159	0.02074342
0.18631461	0.2352705	0.037490536		0.02420704	0.02696193	0.02832315
0.13296616	0.0798745	0.026360082		0.01727571	0.00915359	0.01991438
0.16592669	0.2380116	0.043296706		0.02155812	0.02727606	0.03270957
0.20301638	0.2208984	0.054304145	$\times$ **W**	0.02637702	0.02531489	0.04102541
0.2242308	0.2983807	0.069983945	➔	0.02913332	0.03419434	0.0528711
0.19595813	0.1110996	0.045192224		0.02545998	0.01273198	0.03414158
0.25098933	0.1733151	0.076317065		0.03260994	0.01986186	0.05765561
0.2962117	0.1616906	0.097998608		0.03848548	0.01852969	0.07403547
0.27667341	0.2641162	0.125342749		0.03594696	0.03026763	0.09469328
0.09997257	0.1247483	0.063244267		0.012989	0.01429612	0.04777944
0.09350609	0.2425485	0.112708157		0.01214883	0.02779599	0.08514816
0.19284391	0.2936661	0.16685824		0.02505536	0.03365405	0.12605718
0.27305338	0.2361842	0.203757506		0.03547662	0.02706664	0.15393364
0.20096998	0.1761578	0.264920736		0.02611114	0.02018763	0.20014092
0.18439384	0.1727948	0.401028156		0.02395748	0.01980223	0.30296663
0.27945374	0.2051748	0.463008657		0.03630819	0.02351297	0.34979133
0.16593991	0.252187	0.632280475		0.02155984	0.02890056	0.47767191

Table 14. Positive and negative ideal solutions

V_j^+	0.00025743	0.03936159	0.00600752
V_j^-	0.04116618	0.00653004	0.47767191

Step 6: Ranking of options: The better option is the one whose Cl_i is greater. The calculations related to Steps 4, 5 and 6 are shown in Table 15. According to the calculations, the best set of answers is for scenario 7 with $n_i = 15$ and $j_{max} = 50$. Figure 4 shows the solution set.

Table 15. Final ranking

Item	d_i^+	d_i^-	Cl_i	Rank	Item	d_i^+	d_i^-	Cl_i	Rank
1	0.47168	0.47168	0.90406	12	14	0.04622	0.44385	.9057	10
2	0.46712	0.46712	0.91919	8	15	0.06399	0.42032	0.86788	15
3	0.45668	0.45668	0.93497	2	16	0.08077	0.40382	0.83333	16
4	0.44615	0.44615	0.91799	9	17	0.09603	0.38375	0.79985	18
5	0.37426	0.37426	0.78303	19	18	0.05035	0.43089	0.89537	13
6	0.46962	0.46962	0.93205	4	19	0.08086	0.39417	0.82978	17
7	**0.46418**	**0.46418**	**0.95011**	**1**	20	0.12272	0.35303	0.74205	20
8	0.45827	0.45827	0.93445	3	21	0.15256	0.32444	0.68017	21
9	0.45013	0.45013	0.92785	5	22	0.19678	0.27827	0.58577	22
10	0.45839	0.45839	0.92465	7	23	0.29855	0.17605	0.37095	23
11	0.44588	0.44588	0.92485	6	24	0.34603	.1291	0.27171	24
12	0.4373	.4373	0.90503	11	25	0.47226	0.02975	0.05926	25
13	0.42587	0.42587	0.8851	14					

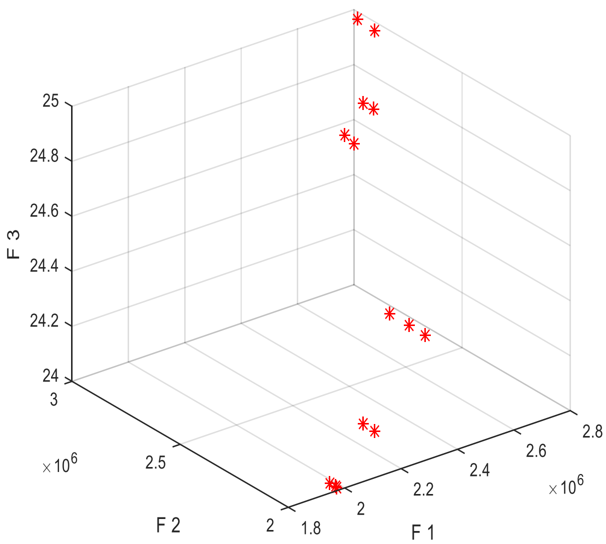

Fig. 4. Selected Pareto solution set

6. Conclusions

In this research, a network related to the collection and treatment centers in the closed-loop supply chain process was designed by a new mixed nonlinear multi-objective integer mathematical model. It is worth noting that three types of treatment were considered: physical, thermal, and biological treatments. In this model, three objective functions were considered and included profit maximization, emission minimization, and minimization of the number of facilities under construction. This model was obtained after determining the number of collection and treatment centers, the number of waste storage containers, the amount of waste sent from collection centers to treatment centers, and the areas covered by collection centers. Due to the conflicting objective functions, a corrected NSGAII algorithm was used to solve this model. The amount of S in the proposed NSGAII method was less than the amount of S in the simple NSGAII method which showed improvement of the proposed procedure; also, the value of D in the proposed NSGAII method was equal to the amount of D in the simple NSGAII. In order to select the best set of Pareto solutions, the TOPSIS technique was used. The indicators used for assessment were S, D, and runtime. The indicators of S and runtime had a negative aspect and the D index had a positive aspect. According to the calculations, 25 different scenarios were analyzed in the numerical example and the best solution belonged to scenario 7 where $n_i = 15$ and $j_{max} = 50$. Due to the inherent uncertainty in the model parameters, the use of random variables in the model is proposed for future research. It is also recommended to compare the proposed procedure with other meta-heuristics methods.

References

[1] 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*(1), 328-344.

[2] Govindan, K., Soleimani, H., Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European journal of operational research*, *240*(3), 603-626.

[3] 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 and chemical engineering*, *66*, 151-164.

[4] Hatefi, S. M., Jolai, F. (2014). Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions. *Applied mathematical modelling*, *38*(9), 2630-2647.

[5] Validi, S., Bhattacharya, A., Byrne, P.J. (2012). Greening the Irish food market supply chain through minimal carbon emission: an integrated multi-objective location-routing approach. In: *Proceedings of the 10th international conference on manufacturing research*, Aston University, UK, pp. 805-810.

[6] Subramanian, P., Ramkumar, N., Narendran, T. T., Ganesh, K. (2013). PRISM: Priority based Simulated annealing for a closed loop supply chain network design problem. *Applied soft computing*, *13*(2), 1121-1135.

[7] 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*, *68*(1-4), 917-931.

[8] Pazhani, S., Ramkumar, N., Narendran, T. T., Ganesh, K. (2013). A bi-objective network design model for multi-period, multi-product closed-loop supply chain. *Journal of industrial and production engineering*, *30*(4), 264-280.

[9] Fallah-Tafti, A. L., Sahraeian, R., Tavakkoli-Moghaddam, R., Moeinipour, M. (2014). An interactive possibilistic programming approach for a multi-objective closed-loop supply chain network under uncertainty. *International journal of systems science*, *45*(3), 283-299.

[10] Validi, S., Bhattacharya, A., Byrne, P. J. (2014). Integrated low-carbon distribution system for the demand side of a product distribution supply chain: a DoE-guided MOPSO optimizer-based solution approach. *International journal of production research*, *52*(10), 3074-3096.

[11] Validi, S., Bhattacharya, A., Byrne, P. J. (2014). A case analysis of a sustainable food supply chain distribution system—A multi-objective approach. *International journal of production economics*, *152*, 71-87.

[12] Garg, K., Jain, A., Jha, P. C. (2014). Designing a closed-Loop Logistic Network in Supply Chain by Reducing its unfriendly consequences on environment. In *Proceedings of the second international conference on soft computing for problem solving (SocProS 2012), December 28-30, 2012* (pp. 1483-1498). Springer India.

[13] Validi, S., Bhattacharya, A., Byrne, P. J. (2015). A solution method for a two-layer sustainable supply chain distribution model. *Computers and operations research*, *54*, 204-217.

[14] Keshtzari, M., Naderi, B., Mehdizadeh, E. (2016). An improved mathematical model and a hybrid metaheuristic for truck scheduling in cross-dock problems. *Computers and industrial engineering*, *91*, 197-204.

[15] Lin, C., Choy, K. L., Ho, G. T., Chung, S. H., Lam, H. Y. (2014). Survey of green vehicle routing problem: past and future trends. *Expert Systems with applications*, *41*(4), 1118-1138.

[16] Luque-Almagro, V. M., Moreno-Vivián, C., Roldán, M. D. (2016). Biodegradation of cyanide wastes from mining and jewellery industries. *Current opinion in biotechnology*, *38*, 9-13.

[17] Panicker, V. V., Vanga, R., Sridharan, R. (2013). Ant colony optimisation algorithm for distribution-allocation problem in a two-stage supply chain with a fixed transportation charge. *International journal of production research*, *51*(3), 698-717.

[18] Hasani, A., Zegordi, S. H., Nikbakhsh, E. (2015). Robust closed-loop global supply chain network design under uncertainty: the case of the medical device industry. *International journal of production research*, 53(5), 1596-1624.