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A multi-objective mathematical model for designing an environmentally friendly supply chain

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Abstract

The term sustainable or green supply chain refers to integrating environmentally sustainable processes into the traditional supply chain. It can include material selection and purchase, product procurement, product design, manufacturing and assembly, distribution, and end-of-life management. Undoubtedly, reducing air pollution, water, and waste management is the primary goal of a green supply chain. Green operation examines the performance of companies in terms of producing less waste, reusing and recycling products, and reducing production costs. In this research, as it is known, the problems of green supply chain network design are in the category of NP-Hard problems. Therefore, a multi-objective genetic algorithm (NSGA-II) will be used in this research to solve large-scale problems. Our primary goal in this research is to provide a multi-objective mathematical model with five indicators: location, selling price, average shortage, transportation, and costs, to design an environmentally friendly supply chain to reduce carbon dioxide (CO2) emissions.

Keywords: environment, supply chain, green supply chain, carbon dioxide, meta-heuristic algorithm, multi-objective genetic algorithm

1- Introduction

Today, along with the fast and accelerated growth of the industry worldwide, products' environmental and ecological effects have become a critical issue. Serious concern about the environmental impact and increased risks caused by industrial activities for human health has led to increased research on green supply chain management. Today, due to the rapid and very high industrialization process of the world and the environmental effects of goods, the topic of green supply chain has received much attention. The green supply chain is one of the optimal and valuable solutions to preserve the environment and improve the planet's current conditions. In recent years, supply chain management has become something beyond an essential area of research by adapting the field of study and various theories involved in engineering, sales, marketing, strategic management, logistics, and economics. In other words, the green supply chain has become a complex, practical, and critical process. Production with minimal environmental damage has become one of the serious goals of industries, which has led to the formation of the concept of green supply chain as a concept that has elements of

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sustainability and a combination of global environmental thinking and upstream and downstream members of a management community (Setiawan et al., 2021).

In today's world, green supply chain managers in leading companies try to benefit from green logistics and improve their environmental performance in the entire chain by creating harmony, desirability, and environmental satisfaction throughout the supply chain to gain a sustainable competitive advantage. Base their goals on three crucial issues and axes of green design (product), green production (process), and product recycling (Yakavenka et al., 2020). In the green supply chain, each member provides information and scientific and technical support for other components to achieve environmental goals. This partnership enables the supply chain to achieve its objectives, such as cost minimization, customer satisfaction, and health benefits. By adding the word green, green supply chain management is introduced, which refers to humanitarian aid, green production, green distribution, and reverse logistics. The green supply chain has new dimensions of green design, procurement, sourcing, production, packaging, marketing, distribution, purchasing, and reverse logistics. The green supply chain is a new approach to reducing waste, minimizing pollution, saving energy, protecting natural resources, and reducing the emission of harmful gases, including reducing the emission of carbon dioxide (CO2) (Ehtesham Rasi & Sohanian, 2021).

The term sustainable or green supply chain refers to integrating environmentally sustainable processes into the traditional supply chain. It can include material selection and purchase, product procurement, product design, manufacturing and assembly, distribution, and end-of-life management. Undoubtedly, reducing air pollution, water, and waste management is the primary goal of the green supply chain; green operation examines the performance of companies in terms of producing less waste, reusing and recycling products, and reducing production costs. In this research, as it is known, the design problems of the green supply chain network are included in the category of NP-Hard problems. Therefore, a multi-objective genetic algorithm (NSGA-II) will be used in this research to solve large-scale problems. Our primary goal in this research is to provide a multi-objective mathematical model with five indicators: location, selling price, average shortage, transportation, and costs, to design an environmentally friendly supply chain to reduce carbon dioxide (CO2) emissions.

2- The importance and necessity of research

The globalization of the economy and the development of information technology have changed the supply-oriented market to the demand-oriented market, and organizations have realized the importance of satisfying customers' needs to maintain and survive. Based on this, supply chain management became important because satisfying customers' needs and interests is done by the final product and other upstream suppliers. In the conventional view of the past, supply chain management included directing all supply chain members in an integrated and coordinated manner to improve performance to promote greater productivity and profit. Therefore, supply chain managers were looking for faster delivery of goods and services, cost reduction, and quality improvement. However, improving the environmental performance of the supply chain and the importance of social costs and environmental destruction should be considered. With the pressure of government regulations to obtain environmental standards on the one hand and the growing demand of customers to supply green products (without harmful effects on the environment), the concept of a green supply chain and its management emerged. Today, green supply chain managers in leading companies try to use green logistics and improve their environmental performance in the entire supply chain as a strategic weapon to gain an advantage by creating environmental benefits and satisfaction throughout the supply chain. To benefit from sustainable competition and base their goals on three essential issues: green design (product), green production (process), and product recycling.

Nahr et al. (2021). In an article, they investigated "robust optimization for a double-objective green closed-loop supply chain with the heterogeneous transportation system and considering pre-sorting." Nozari et al. (2021). In a paper, they addressed "Designing a multi-stable multi-product delivery routing network for the two-tier supplier selection problem in B2B e-commerce platform". This paper examines the environmental impacts produced by multi-vehicle transportation.

Lotfi et al. (2016), in an article "Optimization of multi-cross systems with multiple objectives of green location routing problem considering carbon emission and energy consumption," were investigated. Cross-connecting is an excellent way to reduce the space needed to store goods, inventory, management costs, and customer order lead times. This paper focuses on cost optimization, inbound and outbound truck scheduling, and green supply chains with multiple connections. Fallah et al. (2021), in an article titled "Sustainable Supply Chain Network Model, Carbon Neutrality and Personalization," a study was conducted to discover a new sustainable supply chain network type. In this research, the design of a closed-loop logistics network was presented to reduce pollution and environmental pollution by using the Bertsimas and wire stabilization method. The mathematical model presented in this research considers the goals of minimizing transportation costs, minimizing the time of receiving raw materials from the supplier, and minimizing the time of returning the product from the customer to the separation center.

Nahr et al. (2021) discussed this in the article "A Systematic Literature Review of Quantitative Models for Sustainable Supply Chain Management." The main objective of this study is to present a combination of critical elements of quantitative model proposals that use sustainability indicators in the design and management of future supply chains. In an article, Nozari et al. (2021) discussed "designing a multi-objective green supply chain network for an automobile company using an improved meta-heuristic algorithm." The purpose of this paper is to present a five-layer multi-product green supply chain network for an automobile company. The proposed green supply chain network includes different levels, such as suppliers, warehouses, factories, distribution centers, and customers.

Ali Ahmadi et al. (2016), in an article, addressed "Green closed-loop supply chain network design considering cost control and CO2 emissions". An environmental integer programming model is developed to balance environmental impact control and operational cost reduction. Mohammadi et al. (2015), in an article, investigated "meta-heuristic algorithms to solve the problem of designing a sustainable agricultural grain supply chain network." In this paper, a mixed integer nonlinear programming (MINLP) model is proposed to understand the significant complications associated with the two-tier food grain supply chain along with sustainability aspects (carbon emissions). Table 1 shows the existing research gap.

Table 1: Research gap

Author	**Year**	**locating**	**Selling price**	**Transportation**	**Costs**	**Green supply chain**	**Reducing carbon dioxide**	**Method**
Sigüenza et al	2021					✓		a review
Zhong et al.	2021				✓	✓	✓	panel
Pak et al.	2021			✓	✓	✓	✓	Metaheuristics of NSGA II and SPEA II in sample problems d
Xu et al.	2021					✓		a review
Goodarzian et al	2020					✓		Genetic algorithm and new hybrid particle swarm optimization
Alkhayyal	2020				✓	✓	✓	modeling
Dwive et al	2020	✓		✓		✓	✓	Genetic Algorithm (GA) and Quantum Based Genetic Algorithm (Q-GA)
Huang et al	2020	✓			✓	✓	✓	Scenario-based method and epsilon method
Current article	2022	✓	✓	✓	✓	✓	✓	Multi-objective genetic meta-heuristic algorithm

3- Mathematical modeling

The current research is applied in terms of its purpose since its results are used to design an environmentally friendly supply chain that reduces carbon dioxide.

3.1. hypotheses of the model

The assumptions of the research are as follows:

- The number of recycling facilities to be built has not been determined.
- There is no limit on the capacity of transportation systems.
- The presented model is multi-period and multi-product.
- The probability of defects in products is greater than zero.
- The number of facilities to be built has not been determined
- The amount of CO2 emissions is ambiguous.
- All potential locations of distribution centers, collection centers, recycling, and recovery centers are discrete.
- The capacity of facilities (production center, suppliers, recycling center, and recovery center) is limited.
- The location of customer centers for recycled materials is fixed.

Figure 1 shows the supply chain schematic.

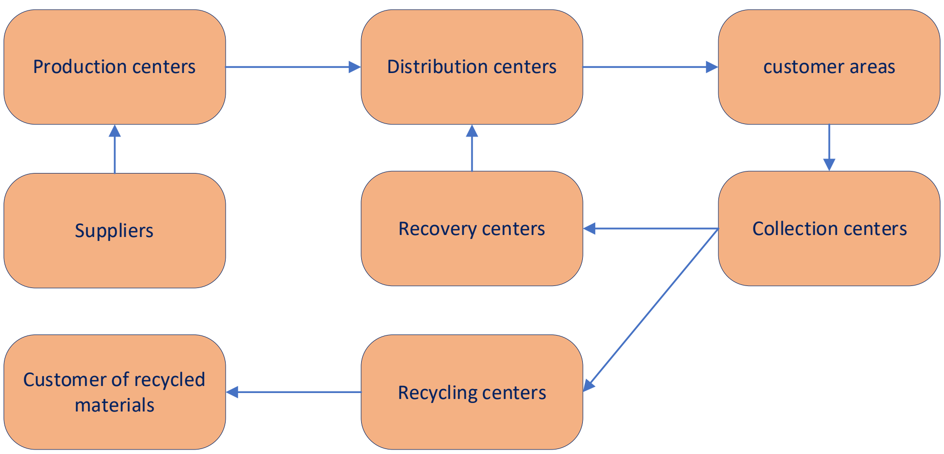

Figure 1: Schematic of the supply chain presented in the research

3.2. formulation

Sets

i	Set of suppliers
j	Set of products
r	A set of candidate locations for the construction of distribution centers
v	Set of customer locations
g	Candidate centers for collection
m	Candidate set for recovery centers (or repair centers for reuse)
n	A set of candidate locations for recycling centers
p	Set of transport modes
t	A set of periods

Parameters

cap_{ji} Capacity of supplier i of product j

d_{jkt} Customer k's demand in period t for product j

pt_j Time required to produce product j

$time$ Total time available

r_{jkt} Amount of product j wasted by customer k in period t

w_{jkt} Return percentage rate of product j from customer k in period t

La Any large number

Fr_j The percentage of raw materials that can be obtained from product j

vo_j Product volume j

$sale_{ji}$ Selling price of supplier i of product j

e_j Failure cost per unit for product j

f_{ji} Defect rate for product j from supplier i

tr_{jip} Transportation cost from supplier i to factory for product j for transportation type p

$cost$ The cost of buying a car for the factory

tr^2_{rjp} The cost of transfer from the factory to the distributor r with transportation p

tr^3_{jrkp} The cost of transfer from the distributor r to the customer k in the period t and for the mode of transportation p

CF_{jm} Remanufacturing cost per unit j at recovery center m

CF^2_{jn} The cost of transporting recycling in unit j at the recycling center n

CF^3_v The price of each unit of raw materials by the customer of recycled materials v

tr^5_{jgmp} The cost of transfer from the collection center g to the repair center m in the mode of transportation p

tr^6_{jmrp} The cost of moving from the repair center m to the distribution center r is the transportation mode p

fix^1_g The fixed cost of the collection center g

fix^2_m The fixed cost of the repair and improvement center m

fix^3_n Fixed cost of recycling center n

tr^7_{nvp} The cost of transportation from the recycling center to the customer of recycled materials v for mode of transportation p

$sale_{ji}$ Selling price of product j from supplier i

Q^1_{jrp} The amount of greenhouse gas emissions to transfer a unit of product j from the factory to the distributor r with transportation p

Q^2_{jrkp} The amount of greenhouse gas emissions to transport a unit of product j from distributor r to customer k with transportation p

Q^3_{jkgp} The amount of greenhouse gas emissions for transporting a unit of product j from the customer k to the collection center g with transportation p

Q^4_{jgmp} The amount of greenhouse gas emissions for transporting a unit of product j from the collection center g to the repair center m to the factory with transportation p

Q^5_{jgnp} The amount of greenhouse gas emissions for transporting a unit of product j from the collection center g to the recycling center n to the factory with transportation p

Q^6_{jmrp} The amount of greenhouse gas emissions for transporting a unit of product j from the repair center m to the distributor r in the mode of transportation p

Q_{nvp}^{7} The amount of greenhouse gas emissions to be transferred from recycling centers n to the customer of recycled materials v in the mode of transportation p

Decision variables

A_g^1 variable zero and one; If the collection center g is built, equal to one and zero otherwise

A_m^2 variable zero and one; If repair center m is built, it is equal to one and zero otherwise

A_n^3 Variable zero and one; equal to one if recycling center n is built and zero otherwise

x_{jitp} The amount of product j sent from supplier i to the factory in the period t and in the mode of transportation p

x_{jrtp}^2 The amount of product j sent from the factory to the distributor r in the period t and in the mode of transportation p

x_{jrktp}^3 Quantity of product j shipped from distributor r to customer k in period t and in mode of transportation p

x_{jkgtp}^4 The amount of product j sent from customer k to collection center g in period t and mode of transportation p

x_{jgmtp}^5 The amount of product j sent from the collection center g to the repair center m in the period t in the mode of transportation p

x_{jgntp}^6 The amount of product j sent from the collection center g to the recycling center n in the period t in the mode of transportation p

x_{jmrtp}^7 Quantity of product j shipped from repair center m to distribution center r in period t in transportation mode p

x_{nvtp}^8 The amount of product j shipped from the recycling center n to the recycled material customer v in the period t in the mode of transport p

u_{nvtp} The amount of raw materials transferred in transport mode p from recycling centers n to the customer of recycled materials v in the period t

z_{jt} The amount of product j produced in the factory in the period t

NM The number of machines used in the factory

mr_{jmt} The amount of product collected j in the recovery center m in the period t

i_{jnt} Number of product j at recycling center n in period t

Mathematical model:

Objective functions

$$\begin{aligned}\min z_1 = &\sum_r\sum_j\sum_p\sum_t x_{jrtp}^2 \times Q_{jrp}^1 + \sum_r\sum_k\sum_j\sum_p\sum_t x_{jrktp}^3 \times Q_{jrkp}^2 \\ &+ \sum_k\sum_g\sum_j\sum_p\sum_t x_{jkgtp}^4 \times Q_{jkgp}^3 \\ &+ \sum_g\sum_m\sum_j\sum_p\sum_t x_{jgmtp}^5 \times Q_{jgmp}^4 \\ &+ \sum_g\sum_n\sum_j\sum_p\sum_t x_{jgntp}^6 \times Q_{jgmp}^5 \\ &+ \sum_m\sum_r\sum_j\sum_p\sum_t x_{jmrtp}^7 \times Q_{jmrp}^6 \\ &+ \sum_n\sum_v\sum_p\sum_t x_{nvtp}^8 \times Q_{nvp}^7\end{aligned} \tag{1}$$

$$
\begin{aligned}
\min z_2 = & \sum_i \sum_j \sum_p \sum_t x_{jitp} \times sale_{ji} + \sum_i \sum_j \sum_p \sum_t x_{jitp} \times e_j \times f_{ji} \\
& + \sum_i \sum_j \sum_p \sum_t x_{jitp} \times tr_{jip} + \sum_j \sum_t z_{jt} \times pr_j + NM \times cost \\
& + \sum_p \sum_t \sum_j \sum_r x^2_{jrtp} \times tr^2_{rjp} \\
& + \sum_r \sum_k \sum_j \sum_p \sum_t x^3_{jrktp} \times tr^3_{jrkp} \\
& + \sum_r \sum_k \sum_j \sum_p \sum_t x^4_{jkgtp} \times tr^4_{jkgtp} \\
& + \sum_g \sum_j \sum_m \sum_p \sum_t x^5_{jgmtp} \times tr^5_{jgmp} \\
& + \sum_m \sum_r \sum_j \sum_p \sum_t x^7_{jmrtp} \times tr^6_{jmrp} + \sum_g A_g \times fix^1_g \\
& + \sum_m A^2_m \times fix^2_m + \sum_n A_n \times fix^3_n \\
& + \sum_m \sum_j \sum_t mr_{jmt} \times CF_{jm} + \sum_n \sum_v \sum_p \sum_t u_{nvtp} \times tr^7_{nvp} \\
& + \sum_n \sum_j \sum_t i_{jnt} \times CF^2_{jn} + \sum_n \sum_v \sum_p \sum_t u_{nvtp} \times CF^3_v
\end{aligned} \qquad (2)
$$

The first objective function examines the amount of greenhouse emissions.

In the second objective function, the costs of purchasing from suppliers, the cost of defective products purchased from suppliers, the cost of transportation, the cost of construction, the cost of production, the cost of marketing, and the cost of recycling.

Constraints:

$$\sum_p x_{jitp} \le cap_{ji} \qquad \forall i, j, t \qquad (3)$$

$$\sum_r \sum_p x^3_{jrktp} \ge d_{jkt} \qquad \forall i, k, t \qquad (4)$$

$$\sum_j z_{jt} \times pt_j \le NM \times time \qquad \forall t \qquad (5)$$

$$\sum_i \sum_p x_{jitp} + z_{jt} = \sum_r \sum_p x^2_{jrtp} \qquad \forall t, j \qquad (6)$$

$$\sum_p x^3_{jrktp} + \sum_m \sum_p x^7_{jmrtp} = \sum_k \sum_p x^3_{jrktp} \qquad \forall r, t, j \qquad (7)$$

$$\sum_g \sum_p x^4_{jkqtp} \ge r_{jkt} \qquad \forall k, t, j \qquad (8)$$

$$r_{jkt} = w_{jkt} \times d_{jkt} \qquad \forall k,t,j \qquad (9)$$

$$\sum_k \sum_p x^4_{jkgtp} = \sum_m \sum_p x^5_{jgmtp} + \sum_n \sum_p x^6_{jgntp} \qquad \forall q,j,t \qquad (10)$$

$$\theta_j \times \sum_k \sum_p x^4_{jkgtp} = \sum_m \sum_p x^5_{jgmtp} \qquad \forall q,j,t \qquad (11)$$

$$\sum_m \sum_p x^5_{jgmtp} = \sum_r \sum_p x^7_{jmrtp} \qquad \forall m,j,t \qquad (12)$$

$$mr_{jmt} = \sum_m \sum_p x^5_{jgmtp} \qquad \forall m,j,t \qquad (13)$$

$$fr_j \times \sum_n \sum_p x^6_{jgntp} = \sum_v \sum_p u_{nvtp} \qquad \forall m,j,t \qquad (14)$$

$$ir_{jnt} = \sum_n \sum_p x^6_{jgntp} \qquad \forall j,t,n \qquad (15)$$

$$\sum_j \sum_k \sum_p vo_j \times x^3_{jrktp} \le cap^2_r \qquad \forall r,t \qquad (16)$$

$$\sum_j mr_{jnt} \le cap^2_m \qquad \forall m,t \qquad (17)$$

$$\sum_j ir_{jnt} \le cap^3_n \qquad \forall n,t \qquad (18)$$

$$A_g \times La \ge \sum_j \sum_t \sum_p \sum_n x^6_{jgntp} \qquad \forall q \qquad (19)$$

$$A^2_m \times La \ge \sum_j \sum_r \sum_t \sum_p x^7_{jmrtp} \qquad (20)$$

$$the\ the\ A^3_n \times La \ge \sum_j \sum_g \sum_t \sum_p x^6_{jgntp} \qquad \forall n \qquad (21)$$

Constraints number 3 to 21 represent the following, respectively.

3) It ensures that the capacity of the suppliers is respected.
4) It ensures that the customer's demand is satisfied.
5) It calculates the factory's production capacity according to the number of used machines and available time.
6) The amount of production in the factory plus the demand provided by the supplier is equal to the total demand received from the distributors.
7) Check the input and output balance value of each distributor.
8) It balances the input and output of customers.
9) It calculates the amount of product sent to collection centers.
10) Checks the balance of input and output to the collection center.
11) Checks the balance of input and output to the collection center.
12) It checks the balance of input and output to the repair center.
13) It ensures that the collection and recycling centers meet the demand.
14) It ensures that the collection and recycling centers meet the demand.
15) It ensures that the demands are fulfilled in the recycling centers.
16) Check the capacity of the distributor.
17) Check the capacity limitation of repair centers.
18) Check the capacity limitation of recycling centers.

19) It determines which of the collection centers has been built.
20) It determines which of the repair centers has been built.
21) It determines which of the recycling centers has been built.

4- Analysis of data

In this section, we will examine the components of the NSGAII algorithm first and then test its efficiency. Next, we will determine its parameters. Figure 2 shows the pseudocode of NSGA-II.

```
Procedure NSGA-II
Input: N', g, f_k(X) ▷ N' members evolved g generations to solve f_k(X)
Initialize Population P';
Generate random population - size N';
Evaluate Objectives Values;
Assign Rank (level) based on Pareto - sort;
Generate Child Population;
   Binary Tournament Selection;
   Recombination and Mutation;
for i = 1 to g do
    for each Parent and Child in Population do
         Assign Rank (level) based on Pareto - sort;
         Generate sets of nondominated solutions;
         Determine Crowding distance;
         Loop (inside) by adding solutions to next generation starting from
         the first front until N' individuals;
    end
    Select points on the lower front with high crowding distance;
    Create next generation;
       Binary Tournament Selection;
       Recombination and Mutation;
end
```

Figure 2: Pseudocode of NSGA-II

Five numerical examples are presented to check the algorithm's correctness, and the NSGAII algorithm will solve the given examples. The examples were executed ten times, and the average values of the Pareto front were calculated and placed in each house. Then, the best and average answers will be calculated, and the variance and percentage difference of the answers (deviation) will be calculated. Because the deviation values are minimal in both objective functions, the effectiveness of the presented algorithm is proven.

Table 2: Checking the efficiency of the algorithm for the first objective function

	The average solution of the Pareto front of the first objective function															
Example number	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average solution	The best solution	max	min	Deviation of the best and average solutions	Maximum and minimum deviation	Variance
1	85/2	85/1	85/3	85/4	85/1	85/2	85/5	85/4	85/2	85/3	85/27	85/1	85/5	85/1	0/20%	0/47%	0/4
2	125/3	125/1	125/2	125/4	125/3	125/5	125/7	125/9	125/8	125/9	125/5	125/1	125/9	125/1	0/33%	0/64%	0/86

3	175/6	175/9	175/9	176/5	176/9	176/8	177/1	177/3	175/6	177/5	176/5	175/6	177/5	175/6	0/52%	1/07%	1/94
4	258/3	258/8	260/5	261/3	259/4	260/7	259/7	261/4	261/9	260/8	260/3	258/3	261/9	258/3	0/77%	1/37%	2/95
5	376/9	377/3	384/6	378/2	379/6	378/9	380/4	381/5	382/9	383/7	380/4	376/9	384/6	376/9	0/93%	2/00%	7/3

Table 3: Average answers of the Pareto front of the second objective function

	The average solution of the Pareto front of the second objective function																
Example number	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Average solution	The best solution	max	min	Deviation of the best and average solutions	Maximum and minimum deviation	Variance
1	130	130/5	131/1	130/9	131/7	130/3	130/8	131/2	130/9	130/3	130/8	130	131/7	130	0/59%	1/29%	1/31
2	180	180/8	181/2	180/7	181/8	181/1	182/5	181/2	180/9	181/2	181/1	180	182/5	180	0/63%	1/37%	1/63
3	250	252/3	253/1	250/8	253/1	250/4	252/4	252/9	252/4	251/3	251/9	250	253/1	250	0/75%	1/22%	2/91
4	390	393/7	394/2	395/2	392/7	393/2	393/2	392/7	393/2	395/1	393/3	390	395/2	390	0/85%	1/32%	2/90
5	500	502	503/5	505/7	503/7	506/7	507/1	506/4	508/6	506	505	500	508/6	500	0/99%	1/69%	6/08

One of the most essential parts of the algorithm is the setting of parameters related to that algorithm. The parameters of the multi-objective genetic algorithm include the mutation rate and the initial population number. To determine the mutation rate and the number of the initial population, an example was randomly created and solved with the mutation rate and the number of different populations, and the results show that the mutation rate is 0.2 and the population number is between 100 and 150.

5- Conclusion

The term sustainable or green supply chain refers to integrating environmentally sustainable processes into the traditional supply chain. It can include material selection and purchase, product procurement, product design, manufacturing and assembly, distribution, and end-of-life management. Undoubtedly, reducing air pollution, water, and waste management is the primary goal of the green supply chain; green operation examines the performance of companies in terms of producing less waste, reusing and recycling products, and reducing production costs. In this research, as it is known, the design problems of the green supply chain network were included in the category of NP-Hard problems. Therefore, this research used a multi-objective genetic algorithm (NSGA-II) to solve large-scale problems. Our primary goal in this research has been to provide a multi-objective mathematical model with five indicators: location, selling price, average shortage, transportation, and costs, to design an environmentally friendly supply chain to reduce carbon dioxide (CO_2) emissions. The current research is applied in terms of its purpose since its results are used to design an environmentally friendly supply chain to reduce carbon dioxide. Therefore, a multi-objective genetic algorithm (NSGA-II) is used in this research to solve the problem on a large scale.

Five numerical examples were given to check the accuracy of the presented algorithm, and the NSGAII algorithm solved the provided examples. The examples were executed ten times, and the average values of the Pareto front were calculated and placed in each house. Then, the best and average answers were calculated, and the variance and percentage of the answer difference (deviation) were calculated. Because the deviation values were minimal in both objective functions, the effectiveness of the presented algorithm was proven. To determine the mutation rate and the number of the initial population, an example was randomly created and solved with the mutation rate and the number of different populations, and the results showed that the mutation rate was 0.2 and the population number was between 100 and 150.

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