



Green Supply Chain Network Design Under Uncertainty Conditions with the Mathematical Model and Solving it with a NSGA II Algorithm

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ARTICLE INFO	ABSTRACT
<p><i>Received: 8 July 2021</i></p> <p><i>Reviewed: 5 August 2021</i></p> <p><i>Revised: 22 August 2021</i></p> <p><i>Accept: 15 September 2021</i></p>	<p>Purpose: In this paper a mathematical model for the green supply chain network problem is designed. In this research, we seek to optimize two inconsistent and conflicting goals of the problem which are as follows: 1. Minimization of costs 2. Minimization of environmental impacts, using of the economic indicator 99 method.</p> <p>Methodology: In this paper, two methods of Epsilon constraint and NSGA II algorithm are used to solve the two-objective model with the objective functions of minimizing network costs and minimizing emissions.</p> <p>Findings: The results show that the introduced NSGA II algorithm has a high efficiency in forming efficient solutions in a short time.</p> <p>Originality/Value: In this paper, a two-objective model for green supply chain network is modeled and solved with the aim of reducing network costs and reducing greenhouse gas emissions.</p>
<p>Keywords: <i>Green supply chain, Multi-objective optimization, Cost, Eco-indicator 99.</i></p>	

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1. Introduction

Supply chain a term that is widely used nowadays includes all activities in the field of production and distribution the final product with providing service from the earliest stage (providing raw materials) to the final stage (delivery to the customers). Supply Chain Management (APICS) in the dictionary is used for design, plan, execute, control and monitor supply chain activities. Some of the most important goals of the supply chain are building net value, creation of a comprehensive infrastructure, exert influence on logistics around the world, coordination between supply and demand, and performance measurement [1]. Supply chain management which encompasses all activities related to the flow of goods conversion from raw material to material that can be delivered to the consumers across with the flow of information throughout the supply chain, has a significant impact on the environment. Nowadays, in all industries decision making in supply chain management is especially important because of short life time of products and diversification of products. Addressing the green supply chain is important from the following perspectives [2]:

- ✓ Creating desirability and satisfaction in environmental aspect all over the supply chain and achieving a new market through supplying environmentally friendly products
- ✓ Reducing costs through saving resources, fuel costs, job hours of workers, eliminate waste and improve productivity
- ✓ Benefit from competitive advantages through creating and providing value for customers and customer satisfaction and loyalty to the products and finally increasing the profitability of the organization

The management of green supply chain tries to change the traditional linear chain model from the suppliers to the users, also tries to integrate recycling economics into supply chain management. By doing this, we can have a closed loop with a cyclic chain mode [3]. If the company uses green supply chain management, not only can solve environmental problems, but also it will achieve relative success in competitive advantage. In addition, implementing green supply chain management can avoid green barriers to international trade. So it is necessary to implement green supply chain management as quick as possible in order to gain opportunities, dealing with challenges, and succeed. Many large companies such as General Motors (GM), Hewlett-Packard (HP), Procter & Gamble (P&G), Nike (NIKE) and many more, gained good fame and brand for their green products through research and implementation of green supply chain management [4]. According to the done researches, by adding a three-letter word to supply chain management, the capabilities of this correct model have been emphasized once again. "Green" is an extension that has turned this concept into green supply chain management, meaning that by implementing green policies along the supply chain, we can see the transfer of cleanliness and health between the organization to the environment, individual, and the other organizations, and can have an environmental perspective to supply chain [5, 6].

Evidence suggests that due to the needs of customers and the pressures of international and governmental organizations supporting environmental problems, make organizations to react the necessity of environmental management and they have implemented green supply chain management in order to compete with global markets. To explain this concept by definition, of course, evidence suggests that organizations have responded for several years to meet the needs of customers as well as the pressures of international and governmental organizations supporting environmental problems and the need for environmental management have accepted and implemented green supply chain management to compete with global markets [7]. Many purchasing companies demand that their suppliers implement green supply chain management methods and even done additional environmental

requirements [8]. The importance of this problem globally is so much that the suppliers are under the high pressure without using green supply chain management methods in finding any business opportunities in a new environment. The environmental aspect of view to the supply chain can be discussed in any country, any industry and at any level. Therefore, according to the stated content, we present a mathematical model for green supply chain network that not only takes into account the uncertainty in demand, but also minimizes the environmental impact of the supply chain.

2. Theoretical Foundations

Over the past two decades, managers have witnessed a period of change in the world due to the advances of the technology, the internationalization of markets, and the potential state of political economy. The increase of the number of competitors in the global market has forced organizations to improve the Intra-organizational processes in order to continue competing in the global competition arena. In 1960s a significant development formed in competitive organizations in which infrastructures as well as the codification of market strategies focused on "customer satisfaction". They have achieved the principle in which the requirements of achieving market needs and gain greater market share are robust engineering and designing and cohesive production operations [9]. Therefore, Designers were forced to incorporate the ideals and needs of customers into the design of their products, in fact they can launch products with the highest possible quality level, with minimum cost, along with the desired ideals of customer. The purpose of green supply chain is not only the environmental protection, but also nowadays this concept is recognized as a competitive advantage and a commercial value that can also play a role in success of any business.

So much researches have been done in the field of various aspects of green supply chain. In study by Zhang et al. a comprehensive overview on green design is done. Various aspects of green supply chain, such as recyclability, planning and controlling of production in order to remanufacturing, green production, and product recycling can be used [10]. Srinivas C., Rao in their research express that the dominant approach has been used to solve problems related to the supply chain is the using of mathematical modeling. Mathematical modeling is the description of a system using the concepts and language of mathematics. Since in supply chain designing different goals are considered and also, some of studies have addressed the problem of green supply chain design in conditions of uncertainty, so according to these researches conducted in the field of green supply chain network design, with considering multiple goals and simultaneously the demand instability we can make the problem model more realistic and it lead to more accurate results for using by decision makers [11]. In an article, Yao et al. suggested a new optimizing and configuring approach to green supply chains under mass personalizing, and they suggested a new approach to the supply chain configuration, and presented a supply chain planning optimization model to match supply with demand in the research. The results of this study showed that in addition to meet the personal needs of customers about products, it will affect the performance of green management in the entire of the supply chain [12].

Tsao et al., [13] in an article, researched on the design of sustainable supply chain networks in the uncertain environments and suggested a multi-objective mathematical planning model. In this research, an interactive method based on two-phase random programming and probabilistic fuzzy programming has been used to overcome the problems related to uncertainty. Finally, numerical analysis shows the efficiency of the suggested model. Zhen et al. [14] in an article, entitled "Designing a Green and Sustainable Supply Chain Network under Uncertainty", presented an integration perspective for the development of a closed-loop green supply chain network (CLSC) under uncertain demand. To solve

this model, they used Lagrange relaxation method and concluded that the experimental results show the validity and efficiency of the proposed model and the solving method. Also, gained several potentially beneficial managing implications for physicians. Khodadadian et al. [15] in their research, focused on the green supply chain, which includes uncertainty conditions for solving a pattern in order to design a green supply chain network under uncertainty about the future economic conditions in Iran Khodro. Considering the complexity of the research, the meta-heuristic method of genetic algorithm with unlimited sorting (NSGA II) is used to solve the problem and finally, the performance of the model is analyzed with a numeral example with its solution. Ghomi-Avili et al. [16] in a research entitled “The Strong two-level Model for the designing the model of competitive green supply chain network considering inventory decisions under uncertainty” presented a real case of a filter manufacturing company, in which the problem of designing a single product multi-period network for a competitive green supply chain considering pricing decisions and inventory under the risks of uncertainty and disruption, and after modeling the competition and applying pricing decisions by defining price-dependent demand, the risks of disruption through the model are analyzed. And they concluded that the suggested model takes into account the demand uncertainty among the disruption risks and it is able to deal with such uncertainties with implementing such flexibility strategies, such as deciding on inventory and contracting with reliable suppliers. In addition, CO₂ emission control and reverse flow management were added to the model in order to consider environmental problems. Our method to reduce the uncertainty of the problem is to use the probabilistic programming method. Eskandari-Khanghahi et al. [17] in their paper presented a possible optimization model for a multi-period and multi-objective robust blood supply chain with uncertain data due to an uncertain situation during a disaster and after that. In this paper, the constraint method is used to transfer the multi-objective mathematical model to the single-objective model. In order to validate the suggested model, some of test problems have been investigated. For the big problems, a meta-heuristic algorithm (simulated annealing (SA)) is proposed to solve the model. Some numerical examples are solved and evaluated and the performance of the SA algorithm is compared with the Coordination Search Algorithm (HS). Finally, the results are discussed and conclusions are presented. A study entitled "The research on optimization of auto supply chain network robust model under macroeconomic fluctuations" has been conducted. In this research, the designed supply chain network model has been solved using the prohibited search algorithm considering the problem of selecting suppliers and the problem of shipping and distributing products [18]. A multi-objective model for optimizing the design of the supply chain network is presented based on biogeography under uncertainty. In this research, a new two-stage optimization method for designing a multi-objective supply chain network (MO-SCND) with unspecified shipping costs and unspecified customer demands is proposed. In this research, in order to solve the problem, genetic algorithm is used in large scale and Lingo software is used in small scale. After all, for example, a dairy company is presented as a case study to check the applicability of the model [19]. A meta-heuristic, multi-objective approach MBSA is presented for designing and planning of the green supply chain. In the suggested algorithm in this research, the capacities of supply chain entities (factories, warehouses and distribution centers) are planned for the inventory and flow of materials over the time horizon. The purpose of this study was to maximize profits and minimize environmental impacts [20]. Another study presents an optimization model for the green supply chain management using a big data. In this study, three scenarios are proposed to improve green supply chain management. The first optimization scenario is divided into three options: the first option involves minimizing risk (and thus minimizing economic costs); the second option minimizes both risk and carbon emission, and the third option is trying to minimize risk, carbon emission, and economic costs simultaneously [21]. In a similar research, the

problem of designing a multi-stage reactive supply chain network has been raised under two modes of free direct transport and prohibited direct transport. This research, has presented two mathematical models of mixed integers for the two under consideration modes and then, to get rid of the complexity of the mixed integer programming model, the Graph Theoretical Method has been proposed to study of the problem structure. In this research, under consideration model has presented as a Two-Part Graph and for solving the problem, a new method based on graph theory was proposed. To prove the efficiency of the suggested algorithm, the results of the algorithm compared with the exact commercial results [22]. In on another study, the problem of redesigning the multi-level and multi-product supply chain network has been studied. In fact, the problem of redesigning includes the canceling of locating the current facilities and allocating the facilities to the new locations considering the budget constraints, planning objectives, provision of goods by the facility, the level of inventory in warehouses and the flow of products in the network. For this problem, the linear integer programming problem is presented and since this problem is classified as a difficult problem, in order to solve it, a forbidden search algorithm is presented to extract and explore the answer space and changes in network structure, which include relocation, has been prescribed [23]. In another research to design an environmental supply chain network called indeterminate input data, a multi-objective fuzzy mathematical programming method is proposed. The proposed model is able to minimize multiple environmental impacts and also can minimize costs to balance them. In this research, a method based on the life cycle penalty to fine and to restrict various environmental impacts for supply chain network is used. Also, a passive fuzzy method was proposed to solve their model [24]. In a research, a reciprocating supply chain model with an approach of product classification in terms of quality has been presented. In this research, a mixed integer problem is expressed with the aim of maximizing profit and finally the model performance is tested by solving an example by Lingo software [25].

In most of the studies that has been done as yet in the field of the designing of green supply chain network, customer demand has been considered definitively. While such an assumption is not true in many cases and many products have unstable demand. Moreover, in the proposed models, environmental impacts such as environmental impacts of production and transportation of products beside demand uncertainty are not considered. Therefore, in this research, we are trying to provide a model for designing supply chain network with considering the uncertainty on the product demand besides considering the environmental impacts of production and distribution of products. According to the research approach, in order to present the model and solve it, the information obtained from previous researches will be used and it will be conducted in the field.

3. Mathematical Modeling

The considered problem can be formulated in the form of a mixed integer programming model. Before expressing the model, the symbols used for describing the model are presented:

4.1. Indicators

- $p = 1, \dots, P$ Products marker
- $i = 1, \dots, I$ The marker of the potential set of production and recycling locations
- $j = 1, \dots, J$ The marker of the potential set of distribution and inspection locations

$m = 1, \dots, M$	The marker of the set of fixed locations of customer areas
$e = 1, \dots, E$	The marker of the set of waste fixed locations
$L = 1, \dots, L$	Production resources (facilities, human resources, applications, etc.)
$w = 1, \dots, W$	Shopping areas
$d = 1, \dots, D$	Available warehouses
$t = 1, \dots, T$	Production demand program
J^{ss}	A set of distribution centers that must be equipped with a warehouse.
L^{ss}	A set of shopping areas that must be equipped by a distribution center.

4.2. Parameters

d_{kp}	Customer demand for location k from product p
$S1_p$	The average ratio of products p which is sent to the waste unit m
$S2_p$	The average ratio of products p sent to recycling unit j
cw_{ip}	Production center capacity, recycling i per product p
cy_{ip}	Capacity of handling of products p in the forward flow at the distribution center, inspection j
cz_{mp}	Capacity of handling of waste products p in the center of waste m
cwr_{ip}	Capacity of handling of products p in the production center, recycling i
cw_{ip}	Production center capacity, recycling i per product p
C_{pw}^{wh}	Cost control unit for product p in warehouse w
C_{pj}^{jH}	Cost control unit for product p in distribution center j
C_w^W	Fixed annual cost of building a warehouse in a warehouse w
C_j^J	Fixed annual cost of establishing a distribution center j
C_{pi}^p	Production unit cost for p in the production center i
C_{piW}^{TR}	Unit Cost of transferring product p transferred from production center I to warehouse w
C_{pwj}^{TR}	Unit Cost of transferring product p transferred from warehouse w to distribution center j
C_{pjl}^{TR}	Unit Cost of transferring product p transferred from distribution center J to purchase area l
C_{plk}^{TR}	Unit Cost of transferring product p transferred from the shopping area l to the customer location k
C_{pit}^I	Unit Cost of transferring product p inventory in the production center I during period t

C_{pt}^I	Unit cost of product inventory p during period t
C_{pwt}^I	Unit cost of product inventory p in warehouse w during period t
C_{pjt}^I	Unit cost of product p in distribution center J during period t
F_j^{max}	Maximum capacity of distribution center j
F_j^{min}	Minimum capacity of distribution center j
I_{plt}	Demand for product p in the shopping area l during the time period t as scheduled
I_{pit}^{min}	The lowest inventory of product p stored in the production center i at the end of the time period t as scheduled
I_{pwt}^{min}	The lowest inventory of product p stored in warehouse w at the end of the time period t as scheduled
I_{pjt}^{min}	The lowest inventory of product p stored in the distribution center j at the end of the time period t as scheduled
n^{jc}	The minimum inventory stored in the distribution centers expressed as the numbers of days in which materials controlled
n^w	The minimum inventory stored in the warehouses expressed as the numbers of days in which materials controlled
n^p	The minimum inventory stored in production centers expressed as the numbers of days in which materials controlled
ND	Number of production demand programs
P_{pit}^{max}	Maximum production capacity of production center I for product P during the time period t
P_{pit}^{min}	Minimum production capacity of production center I for product P during the time period t
Q_{wj}^{min}	The lowest material flow speed that can be transferred practically and economically from warehouse w to production center j.
Q_{jl}^{min}	The lowest material flow speed that can be transferred practically and economically from distribution center j to shopping area L
Q_{piw}^{max}	Maximum flow speed of product p that can be transferred from production center I to warehouse w
Q_{pwj}^{max}	Maximum flow speed of product p that can be transferred from warehouse w to distribution center j
Q_{pjl}^{max}	Maximum flow speed of product p that can be transferred from the distribution center J to the purchase area l
R_{je}	Full speed of availability of source e in production center I
W_w^{max}	Maximum warehouse capacity w
W_w^{min}	Minimum warehouse capacity w

ΔT_t	The length of the time period t
ei_p^{pro}	Environmental impact of producing a product unit
ei_{ijp}^{pd}	Environmental impact of transporting a unit of product p from location i to location j
ei_{jpk}^{dc}	Environmental impact of transporting a unit of product p from location j to location k
ei_{jip}^{ip}	Environmental impact of transporting a product unit p from location j to location i
ei_{jmp}^{id}	Environmental impact of transporting a unit of product p from location j to location m
ei_{jp}^{in}	Environmental impact of inspecting a unit of product p at location j
ei_{ip}^{re}	Environmental impact of recycling a unit of product p at location i
ei_{mp}^{di}	Environmental impact of disposing of a unit of product p at location m

4.3. Variables

x_{ijp}	The number of products p transported from the production center i to the distribution center j
u_{jkp}	The number of products p transported from distribution center j to customer location k
v_{jip}	The number of products p transported from the distribution center j to the receiving center i
T_{jmp}	The number of products p transported from the distribution center j to the waste center m
W_i	Variable zero and a marker to show whether the production center i is open or close
F_j	capacity of distribution center j
F_w	capacity of Warehouse w
I_{pit}	The inventory amount of product p stored in the production center i at the end of the the time period t
I_{pwt}	The inventory amount of product p stored in warehouse w at the end of the time period t
I_{pjt}	The inventory amount of product p stored in distribution center j at the end of the time period t
P_{pit}	The production speed of product p in the production center i during the time period t according schedule d
Q_{piwt}	The flow speed of product p, transferred from the production center i to the warehouse w during the period of the time t according schedule d
Q_{pwt}	The flow speed of product p, transferred from the warehouse w to the distribution center j during the period of the time t
Q_{pilt}	The flow speed of product p, transferred from the distribution center j to the shopping area l during the period of the time t according schedule d

Q_{plkt}	The flow speed of product p, transferred from the shopping area l to the customer location k during the period of the time t according schedule d
W_w	Warehouse capacity w
Y_w	One, if warehouse w is constructed and otherwise zero
Y_j	One, if distribution center j is constructed and otherwise zero
X_{wj}	One, if the material is transferred from the warehouse w to the distribution center j and otherwise zero
X_{jl}	One, if the material is transferred from the distribution center j to region l otherwise zero
X_{wjt}	One, if the material is transferred from the warehouse w to the distribution center j during the period of the time t otherwise zero
X_{jlt}	One, if the material is transferred from the distribution center j to the shopping area l during the period of the time t otherwise zero
Y_{pw}	The coefficient related to capacity of warehouse w to product inventory p
Y_{pj}	The coefficient related to capacity of distribution center j to product inventory p
P_{pie}	The coefficient of usage speed of source e in production center i to the product p
ψ_s	Probability of product demand during the network period

3.2. Mathematical Model

3.2.1. Objective functions

- First Objective Function (Minimizing The Total Cost)

It minimizes the total costs of designing supply chain network, including: 1- Fixed costs of sites commissioning, 2- Existing maintenance costs, 3- Transmission costs, and 4- Penalty costs for unused capacity. (For example: total cost = fixed costs of commissioning the facility + existing maintenance costs + transfer costs + balancing items over the entire time period). Therefore, cost objective function is formulated as Equation 1

$$\begin{aligned}
\min z_1 = & \sum_t \Delta T_t \left(\sum_w C_w^w Y_w + \sum_j C_j^j Y_j \right) \\
& + \sum_{s=1}^N \psi_s \left(\sum_t \Delta T_t \left(\sum_{p.i} C_{pit}^i P_{pit} + \sum_{p.w} C_{pw}^{wh} \sum_j Q_{pjwt} \right) \right) \\
& + \sum_{p.i} C_{pj}^{JH} \left(\sum_j Q_{pjwt} \right) + \sum_{p.i.w} C_{piw}^{TR} + \sum_{p.w.j} C_{pwj}^{TR} Q_{pwjt} \\
& + \sum_{p.i.i} C_{pjt}^{TR} Q_{pjt} + \sum_{p.l.k} C_{plk}^{TR} + \sum_{p.i} C_{pjt}^I \frac{I_{pjt} + I_{p.j.t-1}}{2} \\
& + \sum_{p.w} C_{pwt}^I \frac{I_{pwt} + I_{pw.t-1}}{2} + \sum_{p.j} C_{pjt}^I \frac{I_{pjt} + I_{pj.t-1}}{2}
\end{aligned} \tag{1}$$

- Second objective function (minimizing the total environmental impacts)

This function minimizes the environmental impacts of the network, including the impacts that the production, distribution, inspection and waste units have on the environment; it also minimizes the pollutants that the transportation unit can enter to the environment. An LCA-based method such as the Eco-indicator 99 method is used to obtain the coefficients used in the equation. The Eco-indicator 99 method is used to estimate the environmental impacts of various supply chain network configurations. To use this method, first of all, the scope of the system and its functional unit and the purpose of using of Eco-indicator must be defined. In this case of study, the scope of the system can be as the boundaries around the supply chain network and the functional unit of the supply chain network, and the functional unit of the supply chain can be determined as satisfying customer demand through producing and distributing products in the forward network and managing low quality returned products in reverse network. Also, the purpose of using Eco-indicator is estimate the environmental impacts of supply chain network configuration. In the second step, the product life cycle must be defined.

Life cycle assessment: During the examining of the environmental impacts of products, just evaluating the designing and producing steps is not enough and it is necessary to examine life cycle of product from the raw material stage to the end of product life. This approach is to evaluate the product life cycle. Life cycle assessment is the process of assessing the impacts that a product has on the environment during its life cycle. This assessment includes the entire product life cycle, processes and activities (extraction and preparation of raw material, manufacturing and production, transportation and distribution, reuse and storage, recycling and final disposal of materials) (Farahani et al., 2013). There are four main methods of life cycle assessment for different conditions:

- 1- From cradle to grave: It is the most common method of life cycle assessment and is used to analyses the type of materials used in making a product. This analysis covers the entire product life cycle.
- 2- From source to wheel: Determines the efficiency of the road transportation system in terms of fuel consumption amount.
- 3- From cradle to gate: considering the assessment of the product cycle until it is delivered to the customer.
- 4- From cradle to cradle: this is a new thinking in life cycle assessment in which, the place of destruction of a product becomes the place of birth of another product. For example, many

recycling companies use high quality paper to produce newspaper and low quality paper to produce thin cardboard [26].

In our case study in the automotive industry field, life cycle steps include the following:

- 1) Production (pro)
- 2) Transportation from production centers to distribution centers (pd)
- 3) Inspection in inspection centers (in)
- 4) Delivering to the customer (dc)
- 5) Transporting to recycling centers (id)
- 6) Transporting to waste centers (id)
- 7) Recycling operation (re)
- 8) Waste operations (di)

Here, the phase of use in customer centers has been omitted from the life cycle steps because it has no effect on decision making variables of the model and thus has no effect on the overall structure of the supply chain network.

In the third step, the materials and processes must be quantified through the product life cycle steps and then, in the fourth step, the final value should be calculated by the following steps:

- 1) Finding the corresponding Eco-indicator
- 2) Multiplying the values in the obtained index value
- 3) Calculating the Sum of the results of the previous step [27].

Based on the above explanations, the second objective function is formulated as equation 2.

$$\begin{aligned} \min z_2 = & \sum_{i,j,p} (e_{ijp}^{pd} + e_{ip}^{pro}) x_{jip} \\ & + \sum_{j,k,p} (e_{j.k.p}^{d.e} + e_{jp}^{in}) u_{jkp} + \sum_{j,m,p} (e_{jip}^{id} + e_{ip}^{re}) v_{jip} + \sum_{j,m,p} (e_{jmp}^{id} + e_{mp}^{di}) T_{jmp} \end{aligned} \quad (2)$$

3.2.2. Limitations

$$\sum_{s=1}^N \psi_s = 1 \quad (3)$$

$$X_{wi} \leq Y_w, \forall w, j \quad (4)$$

$$\sum_w X_{wj} = Y_j, \forall j \in J^{SS} \quad (5)$$

$$X_{wi} \leq Y_j, \forall w, j \notin J^{SS} \quad (6)$$

$$X_{il} \leq Y_j, \forall j, l \quad (7)$$

$$\sum_j X_{jl} = 1, \forall l \in L^{SS} \quad (8)$$

$$Q_{piwt} \leq Q_{piw}^{max} Y_w, \forall p, i, w, t \quad (9)$$

$$Q_{pwjt} \leq Q_{piw}^{max} X_{wj}, \forall p, w, j, t \quad (10)$$

$$Q_{pjlt} \leq Q_{pjlt}^{max} X_{jl}, \forall p, j, l, t \quad (11)$$

$$\sum_p Q_{pwjt} \geq Q_{wj}^{min} X_{wj}, \forall w, j, t \quad (12)$$

$$\sum_p Q_{pjlt} \geq Q_{jl}^{min} X_{jl}, \forall j, l, t \quad (13)$$

$$I_{pit} = I_{pi,t-1} + \left(P_{pit} - \sum_w Q_{piwt} \right) \Delta T_t, \forall p, i, w, t \quad (14)$$

$$I_{pit} = I_{pw,t-1} + \left(\sum_i Q_{piwt} - \sum_j Q_{pwjt} \right) \Delta T_t, \forall p, i, j, w, t \quad (15)$$

$$I_{pit} = I_{pi,t-1} + \left(\sum_j Q_{pwjt} - \sum_l Q_{pjlt} \right) \Delta T_t, \forall p, i, j, l, w, t \quad (16)$$

$$\sum_j Q_{pjlt} = I_{plt}, \forall p, l, t \quad (17)$$

$$P_{pit}^{min} \leq P_{pit} \leq P_{pit}^{max}, \forall p, i, t \quad (18)$$

$$\sum_p \rho_{pie} P_{pit} \leq R_{je}, \forall j, e, t \quad (19)$$

$$W_j^{min} Y_w \leq W_w \leq W_w^{max} Y_w, \forall w \quad (20)$$

$$F_j^{min} Y_j \leq F_w \leq F_w^{max} Y_w, \forall j \quad (21)$$

$$W_w \geq \sum_p y_{pw} I_{pit}, \forall w, t \quad (22)$$

$$I_j \geq \sum_p y_{pj} I_{pit}, \forall j, t \quad (23)$$

$$I_{pit} \geq I_{pit}^{min}, \forall p, i, t \quad (24)$$

$$I_{pjlt} \geq I_{pjlt}^{min} Y_w, \forall p, j, w, t \quad (25)$$

$$I_{pit} \geq I_{pit}^{min} Y_j, \forall p, i, t \quad (26)$$

$$I_{pit}^{min} = \frac{n^p}{7} \sum_w Q_{piwt}, \forall p, i, t \quad (27)$$

$$I_{pjlt}^{min} = \frac{n^w}{7} \sum_j Q_{pwjt}, \forall p, w, t \quad (28)$$

$$I_{pit}^{min} = \frac{n^{jc}}{7} \sum_l Q_{pjlt}, \forall p, i, j, t \quad (29)$$

$$P_{pit} \geq 0, \forall p, i, t \quad (30)$$

$$I_{pit} \geq 0, \forall p, i, t \quad (31)$$

$$I_{pjlt} \geq 0, \forall p, j, t \quad (32)$$

$$I_{pit} \geq 0, \forall p, i, t \quad (33)$$

$$Q_{piwt} \geq 0, \forall p, w, t \quad (34)$$

$$Q_{pwjt} \geq 0, \forall p, m, j, t \quad (35)$$

$$Q_{pjlt} \geq 0, \forall p, i, l, t \quad (36)$$

$$\sum_w C_w^W Y_w + \sum_j C_j^J Y_j \quad (37)$$

$$\sum_{p,i} C_p^P P_{pit}, \forall t \quad (38)$$

$$\sum_{p,w} C_{pw}^{WH} \left(\sum_j Q_{pjwt} \right) + \sum_{p,i} C_{pj}^{jH} \left(\sum_w Q_{pwjt} \right), \forall t \quad (39)$$

$$\sum_{p,i} C_{pit}^I \frac{I_{pit} + I_{pi,t-1}}{2} + \sum_{p,m} C_{pjt}^I \frac{I_{pjt} + I_{pj,t-1}}{2} + \sum_{p,i} C_{pit}^I \frac{I_{pit} + I_{pi,t-1}}{2}, \forall t \quad (40)$$

$$\sum_{p,i,m} C_{pijw}^{TR} Q_{pjwt} + \sum_{p,m,j} C_{pwj}^{TR} Q_{pwjt} + \sum_{p,i,l} C_{pjl}^{TR} Q_{pjlt}, \forall t \quad (41)$$

Eq (3): It is assumed that production demand is defined as fixed actions during the time. The instability of these demands is considered by assumed Qty of schedule $d = 1 \dots ND$. Our purpose is to design a network that can control each of these schedule. Therefore, to reduce the expressed instability, we assume that the probability of program d is defined by ψ_s . Eq (4): Restriction of transferring the materials from distribution center to warehouse (if there is a warehouse): The relationship between warehouse w and distribution center J only can exist when warehouse w is constructed as expressed. Eq (5): Restriction of transferring the materials from distribution center to warehouse (if there is a distribution center) if the warehouse is equipped from the central warehouse. Sometimes it is necessary to equip the special distribution centers from a separate warehouse (separate source) which can be implemented according to the expressed requirements. Eq (6): Restriction of transferring materials from the distribution center to the warehouse if the warehouse is not equipped from the central warehouse. If there is no distribution center then its relationships to warehouses can not exist, this will lead to the expressed limitations. Eq (7): If it is transferred from distribution center to shopping area, if the shopping area is equipped from the distribution center. Eq (8): The previous restriction was written only for distribution centers that they do not have a separate source. For the rest of the distribution centers, the limitations up to equation 6 is sufficient. The relationship between the distribution center J and the shopping point L exists only when the distribution center also exists as expressed. Eq (9): Limitation of the most high speed of materials flow from production center to warehouse during the period exists, if the warehouse was constructed. It is possible to some shopping areas to be equip from separate source (central warehouse). Eq (10): Limitation of the most high speed of materials flow from warehouse to distribution center during the period exists, if the materials were transferred from the warehouse to the distribution center. The flow of the material P from production center I to warehouse w can occur only when the warehouse w exists as expressed. Eq (11): Limitation of the most high speed of materials flow from distribution center to shopping center during the period exists, if the materials of the distribution center were transferred to the shopping area. The above limitations apply to each of schedule d in any time period t , flow of the material P from the warehouse w to the distribution center J occurs only when there is such a mutual connection. Eq (12): Limitation of the most low speed of materials flow

from warehouse to distribution center during the period exists, if the materials are transferred from the warehouse to the distribution center. The flow of the material P from warehouse w to distribution center J occurs only when there is such a mutual connection. Eq (13): Limitation of the most low speed of materials flow from distribution center to shopping center during the period exists, if the materials are transferred from the distribution center to the shopping area. The flow of the material P from distribution center J to shopping area L occurs only when there is such a mutual connection. Eq (14) Limitation of balancing of the materials in progress between production center and warehouse during the time period t . It is thought that in this model inventory may be stored in the different stages of network. This limitation express that the inventory of product P stored at production center I at the end of period t (left side of the equation) is equal to the inventory stored at the end of period $t-1$, and also, any product accumulated at the production center during production during the period, minus any product transferred from production center to warehouses during the period. Eq (15): Limitation of balancing of the materials in progress between warehouse and distribution center during the time period t . Considering that time of producing the product and its transfer in the form of material flow is over than the expressed time, we calculate the total value during the period as $[t-1, t]$. Thus, with multiplying these speeds via period ΔT_t , the domain fluctuates from one week to the several months, which is depending to the actual schedules of the company. Similarly, we can express the 15th and 16th limitations for warehouses and distribution centers. Eq (16): Limitation of balancing of the materials in progress between distribution center and shopping area during the time period t . Eq (17): Limitation of balancing of the inventory level in progress between production center, and the speed of material transfer that is going on in the distribution center and the shopping area during the time period t . Shopping areas typically do not hold inventory amounts for enough time. Therefore, it is assumed that product P, which flows between distribution centers and L shopping areas, is equal to market demand. Eq (18): Limitation of product producing speed. An important problem in the distribution network is the production capacity of the production centers in order to meet customer demands. The production speed of each product in any production center can not exceed specific limitations, so there is always limited production capacity for each product. In addition, there is often a limitation for the speed of production that must be controlled at the time of production at the production center. All of the above are expressed in this limitation which performs to each product and each schedule d and in any period of time t .

Eq (19): Limitation of usage speed of source e . The coefficient of ρ_{pie} expresses the value of source e , which is used by the production center I to produce the product P. This is while R_{je} expresses the speed of the inventory flow of source e in the production center I. Eq (20): Limitation of warehouse capacity. One of the most important problems during the network design is the capacity of warehouses. These values indicate the amount of products that can be stored there over the time period. Capacity w should be generally between special high and low limitations before it will be marketed, should be placed in $W_w^{max} W_w^{min}$ form. This limitation exists in distribution center as well, which expressed below. Eq (21): Limitation of capacity of distribution center. Eq (22) Limitation of capacity of warehouse according to inventory coefficient. In other words, the capacity of warehouses and distribution centers can not be less than the stated inventory that is maintained over the time period. This limitation exists in distribution center as well, which expressed below. Eq (23): Limitation of capacity of distribution center according to inventory coefficient. Eq (24): Limitation of inventory level in production center. Control of the supplying of raw materials is often accompanied by intangible problems of production or unexpected production demands. Surplus inventory always increases operational costs, so it is better

to store raw materials for a short period of time (for example, from a few days to a week). Eq (25): Limitation of inventory level of distribution center if a warehouse is constructed. These limitations ensure that inventory stored in warehouses and distribution centers. The minimum inventory which covers demand, may vary from a schedule to other schedule and from a time to other time. If assume that production, transmission, and demand have constant speed during the time period, inventories are linearly different from time period. This limitation exists in distribution center as well, which expressed below. Eq (26): Limitation of inventory level of production center if a distribution center is constructed. Eq (27): Limitation of the minimum inventory that can be stored in production center on weekdays. n^p, n^w, n^{jc} are the number of days for the production centers, warehouses and distribution centers, respectively, and all materials flow is expressed as tons per week. It is assumed that initial inventories for each product and production of each production center should be at the specified level. This limitation exists in distribution center and shopping area as well, which expressed below. Eq (28): Limitation of the minimum inventory that can be stored in distribution center on weekdays. Eq (29): Limitation of the minimum inventory that can be stored in shopping area on weekdays. Eqs (30- 36): non-negative limitations. Eq (37): Fixed cost of economic infrastructure. The fixed annual cost of constructing a warehouse at location w is represented as c^w_w and has multiplied by double variable Y_w . Therefore, if only warehouse w will be selected, we assume that the production centers have already been constructed, so we do not examine the cost of constructing production center. Eq (38): Production cost includes all costs of the production process. Eq (39): Controlling the cost of materials in the warehouses and distribution centers, and controlling the cost of materials such as packaging wages, insurance and the costs of water, electricity, and etc. usually can not be estimated as fund. Eq (40): The cost of storing inventory in different places. Considering that inventory may be stored in different stages of the network, inventory storing has costs, and in general, the cost incurred during period t is proportional to the average amount of inventory maintenance in this period. The average inventory is expressed by calculating the inventory at the beginning and at the end of the period because the amount of inventory varies linearly in any time period. Eq (41): Transfer cost. The total cost of transfer product P during the period of time t according to schedule D is proportional to the amount of material transferred between the levels. The transfer costs include transfer products between production center and distribution center and between distribution center and the customers.

3.2.3. Limitation of Demand Satisfaction

$$\sum_j u_{jkp} \geq d_{kp} \quad \forall k, p \quad (42)$$

Eq (42): ensures that the demand of all customers will be met.

3.2.4. Limitations of flow balance

$$\sum_i x_{ijp} - \sum_{i,m} (v_{jip} + T_{jmp}) = \sum_k u_{jkp}, \forall j, p \quad (43)$$

$$\sum_k u_{jkp} - (1 - S1_p - S2_p) \sum_i x_{ijp} = 0, \forall j, p \quad (44)$$

$$\sum_m T_{jmp} - s1_p \sum_i x_{ijp} = 0, \forall j, p \quad (45)$$

$$\sum_i v_{jip} - s_{2p} \sum_i x_{ijp} = 0, \forall j, p \quad (46)$$

$$\sum_j v_{jip} - \sum_j x_{ijp} \leq 0, \forall j, p \quad (47)$$

Eqs (43-47): ensure product flow balance at production sites, recycling and inspection centers, and distribution centers in forward and reverse flow.

3.2.5. Limitations of Capacity

$$\sum_j x_{ijp} \leq cw_{ip} w_i, \forall i, p \quad (48)$$

$$\sum_i x_{ijp} \leq cy_{jp} y_j, \forall j, p \quad (49)$$

$$\sum_j v_{jip} \leq cwr_{ip} w_i, \forall i, p \quad (50)$$

$$\sum_j T_{jmp} \leq cz_{mp}, \forall m, p \quad (51)$$

Eqs (48-51): are related to the capacity of production, distribution and waste areas.

3.2.6. Limitations of decision making variables

$$y_j, w_i \in \{0, 1\} \quad (52)$$

$$x_{ijp}, u_{jkp}, v_{jip}, T_{jmp} \geq 0 \quad (53)$$

Eqs (52-53): include the type of decision making variables such as binary or non-negative.

4. Computational results

In this section, the results of numerical solution of the proposed model presented by the exact solution and NSGA II algorithm then their validation and comparison are discussed. To investigate and validate the proposed modeling, first three random samples are created in small, medium and large scales. Also, the parameters are generated randomly using a uniform distribution. The problems are run on a laptop with Intel Core i7 (RAM8 GB) configuration and by GAMS software and CPLEX linear solver. In order to make the problem single target, the exact approach of Epsilon constraint is used. Then, in small-scale problems, the results of the NSGA II algorithm are compared with the results of the exact solution of the model by the CPLEX solver of the GAMS software, and the efficiency of the algorithm is evaluated. Then, since large-scale model solution is not possible, the large-scale problem is solved by the NSGA II algorithm and the solution results will be presented. It should be noted that the genetic algorithm proposed in this research is coded using the MATLAB programming language. Also, it should be noted that the time limit of 3600 seconds is considered to solve the problems by the exact algorithm.

To solve the problem, the definite and robust model implemented for 10 experimental problems in different scales (small, medium, large). It's worth mentioning that problems from 1 to 3 have been considered as small scale problems, from 2 to 6 are medium scale problems and from 6 to 10 large scale problems.

Table 1. The number of different levels of sample problems

Sample number	#P	#I	#J	#K	#M	#E	#L	#W	#D	#T
1	5	2	4	5	2	2	3	2	2	1
2	10	2	7	10	3	4	8	4	3	2
3	14	3	10	20	4	6	18	6	4	2
4	16	5	14	35	8	8	25	8	5	5
5	18	10	20	50	10	10	40	10	7	10
6	20	15	22	70	15	15	55	12	10	15
7	22	20	25	80	20	17	70	14	15	20
8	24	25	27	90	22	20	80	16	17	25
9	26	30	30	100	24	22	85	18	19	30
10	30	35	32	120	25	25	90	20	20	30

Table 2. Distribution of input parameters for sample problems

Parameter	Value	Parameter	Value
d_{kp}	Uniform(10,50)	I_{plt}	Uniform(200,400)
$S1_p$	Uniform(0.1 , 0.2)	I_{pit}^{min}	Uniform(100,500)
$S2_p$	Uniform(0.1 , 0.5)	I_{pwt}^{min}	Uniform(200,600)
cw_{ip} , cy_{jp}	Uniform(100 ,200)	I_{pjt}^{min}	Uniform(150,550)
CZ_{mp}	Uniform(50,200)	n^{jc} , n^w , n^p	Uniform(10,30)
cwr_{ip}	Uniform(100,200)	P_{pit}^{max}	Uniform(2000,5000)
C_{pw}^{wh}	Uniform(10,30)	P_{pit}^{min}	Uniform(100,1000)
C_{pj}^{jH}	Uniform(10,20)	$Q_{wj}^{min} , Q_{jl}^{min}$	Uniform(50,100)
C_W^W	Uniform(100000,500000)	$Q_{piw}^{max} , Q_{pwj}^{max} , Q_{pjl}^{max}$	Uniform(100,2000)
C_j^j	Uniform(200000,700000)	R_{je}	Uniform(50,100)
C_{pi}^P	Uniform(100,200)	W_w^{max}	Uniform(600,1000)
$C_{piw}^{TR} , C_{pwj}^{TR}$	Uniform(20,50)	W_w^{min}	Uniform(300,700)
C_{pjl}^{TR}	Uniform(20,60)	ΔT_t	Uniform(3,12)
C_{ptk}^{TR}	Uniform(30,60)	$e_i^{pro} , e_{ijp}^{pd} , e_{jkc}^{dc}$	Uniform(0,1)
$C_{pit}^I , C_{pt}^I , C_{pwt}^I , C_{pj}^I$	Uniform(10,30)	$e_{jip}^{ip} , e_{jmp}^{id} , e_{jip}^{in}$	Uniform(0,1)
F_j^{max}	Uniform(500,2000)	$e_{ip}^{re} , e_{mp}^{di}$	Uniform(0,1)
F_j^{min}	Uniform(100,200)		

In Table (1), the first column demonstrates the sample number, the second column demonstrates the number of products, the third column demonstrates the number of production and recycling sites, the fourth column demonstrates the number of distribution and inspection sites, the fifth column demonstrates the number of fixed locations of customer areas, and the sixth column demonstrates the number of waste sites and the seventh column demonstrates the number of production resources, the eighth column demonstrates the number of shopping areas, the ninth column demonstrates the number of available warehouses, the tenth column demonstrates the number of production demand schedules and the eleventh column demonstrates the number of time periods in each problem. Also in Table (2), the required parameters for this problem were randomly generated using a uniform distribution at appropriate time intervals. Now, after generating random samples in different scales, the problems are implemented in GAMS software and then with the suggested values, the problems have been implemented in different sizes and after solving the results have been presented in the following tables.

In the suggested Epsilon constraint method, the first objective function is considered as the primary objective function and the second objective function is considered as the sub-objective function; then

10 break points were considered for the second objective function and a total of 10 Pareto points are generated for each problem. In this section, the 10 problems designed in the previous sections, are solved with both objective functions by the Epsilon constraint algorithm and the proposed NSGA II algorithm, and the Pareto based found answers are reported. For example, in Table (3) the Pareto boundary formed by the used two algorithms for the problem 3 can be seen. As is clear, the NSGA II algorithm has managed to find 9 Pareto answers to problem 3. Figure (1) also describes the Pareto points obtained by the two algorithms for the problem 3 as an example of small scale problem.

Table 3. The Pareto optimal solution obtained from solving sample number 3

Classification	Epsilon Constraint		NSGA II	
	The first goal	The second goal	The first goal	The second goal
1	528190	25303	548389	25024
2	534076	24768	558772	25006
3	557170	24638	583328	24983
4	566704	24605	594389	24956
5	568379	24565	597929	24911
6	564997	24483	659254	24688
7	661288	24395	690206	24651
8	677111	24336	699121	24566
9	703139	24325	699842	24520
10	716426	23701	-	-

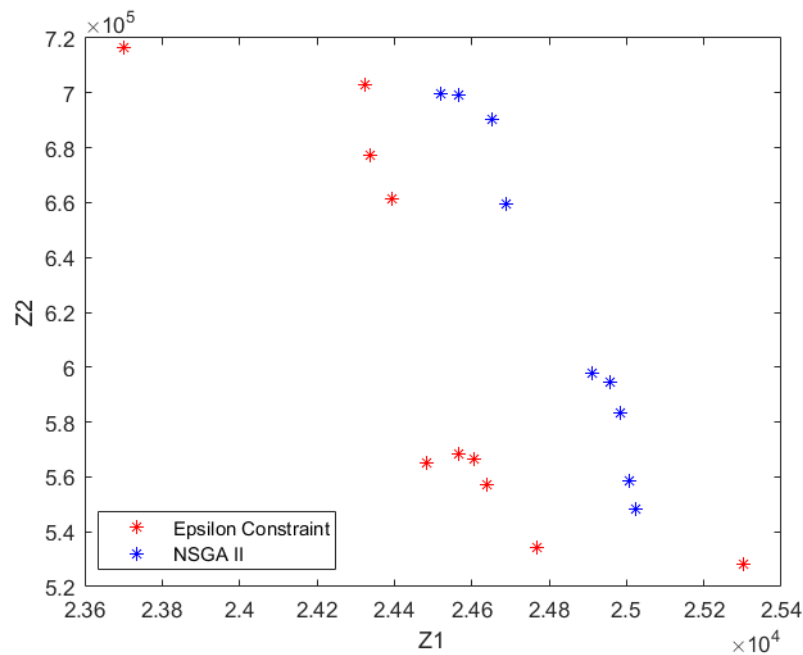


Fig. 1. The created Pareto boundaries in the sample problem 3

According to Figure (1), it is clear that the suggested Pareto boundary by the NSGA II algorithm is very close to the obtained boundary from the exact method of Epsilon Constraint. But for more accurate validation of the proposed algorithm and to find that in what extent this algorithm is able to identify the optimal Pareto boundary, we use the indicators introduced in the previous sections. For this purpose, we calculate the three MID, SM and DM indicators and according to the SAW values resulting from these three indicators, we examine the performance of the proposed algorithm. The calculated values

for the boundaries obtained by the two algorithms for sample problem from 1 to 10 are as shown in Table (4).

Table 4. Results of solving 10 problems

Criterion Problem Method	DM		MID		SM	
	Epsilon Constraint	NSGA II	Epsilon Constraint	NSGA II	Epsilon Constraint	NSGA II
1	1.13	1.02	1.45	1.54	0.54	0.59
2	0.73	0.71	1.07	1.21	0.83	0.89
3	1.27	1.14	1.45	1.69	0.71	0.76
4	1.27	1.21	1.49	1.53	0.54	0.65
5	0.88	0.9	1.33	1.64	0.71	0.68
6	1.17	1.15	1.25	1.43	0.91	0.84
7	1.3	1.66	1.11	1.13	0.88	0.63
8	1.22	1.39	1.59	1.38	1.19	0.91
9	0.93	0.94	2.21	1.94	0.98	0.91
10	1.26	1.87	1.63	1.21	1.59	1.19

The comparison of MID, SM, DM indicators as well as the general comparison of performance of the two algorithms is shown in the Figure (2). According to Table (4) and Figure (2), it is clear that on a small to medium scales (problems from 1 to 6), as far as the exact solving is possible within the time limit of 3600 seconds, the NSGA II algorithm works very close to the Epsilon constraint method. Therefore, the meta-heuristic algorithm used in this research is close to the exact solution and therefore can be a good tool to solve this problem in case of inefficient solution. For example, from problem 2 onwards, the Epsilon constraint method is not able to accurately solve problems within the stated time constraint. Therefore, due to the proper performance of the NSGA II algorithm, this algorithm be used to solve high-dimensional problems.

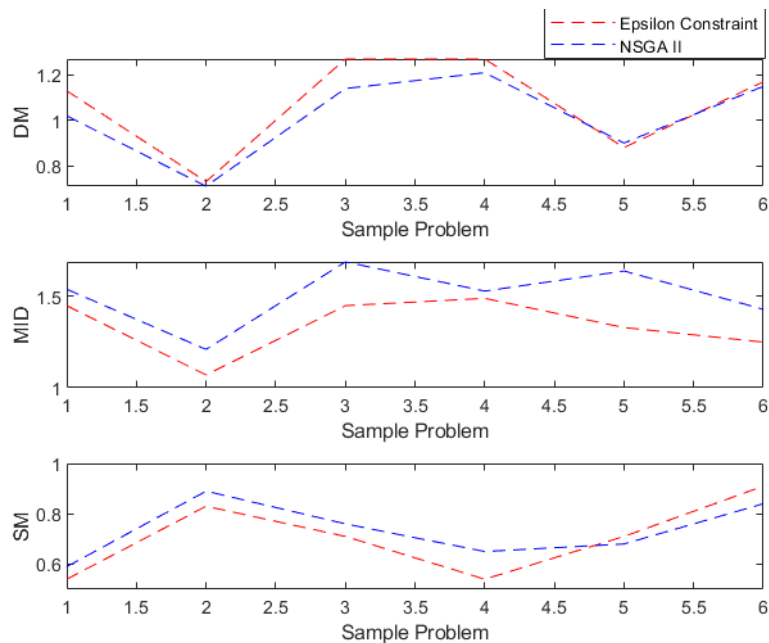


Fig. 2. Index values of DM, MID and SM for the two algorithms in small and medium scales

For distance from the ideal point, the Epsilon Constraint method performed decisively and is better than NSGA II in all respects, which is normal. This means that the Epsilon Constraint method has a better response quality and the boundaries formed by this algorithm are closer to the ideal point. But, according to Table (4), it can be seen that in large scale problems, the Epsilon Constraint method loses its efficiency and the NSGA II algorithm generates better quality answers. In the distance index, neither of the two algorithms decisively performs better than the other. In problems with smaller scales (problems 1 to 4) the Epsilon Constraint method has been more successful. However, with the increase of the scales of the problems and from problem 5 onwards, it can be seen that the NSGA II algorithm generates Pareto answers with a small distance from each other and with the increase of the scales, the performance of the NSGA II algorithm is further improved. In terms of Diversity Index, with increasing the scales of the diversity problem, the answers of NSGA II algorithm increases as well, but in general, they have a very close performance.

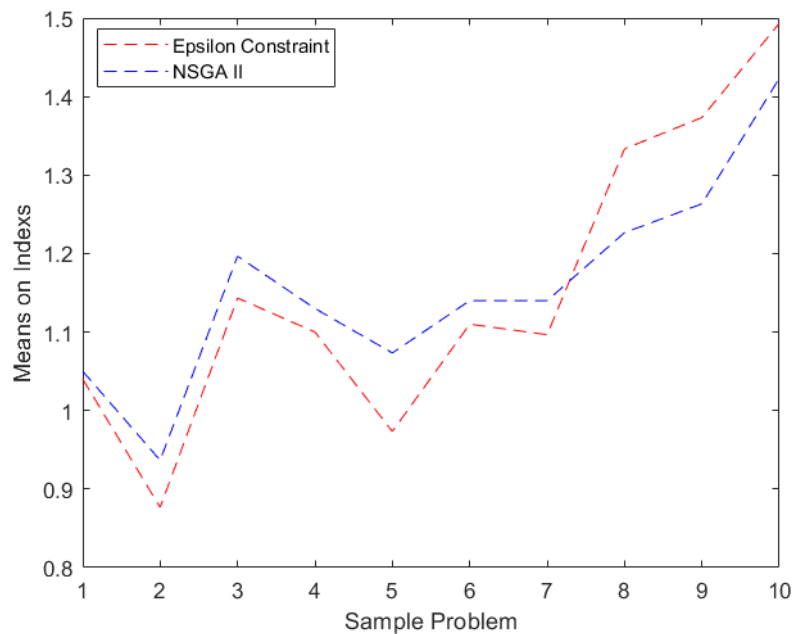


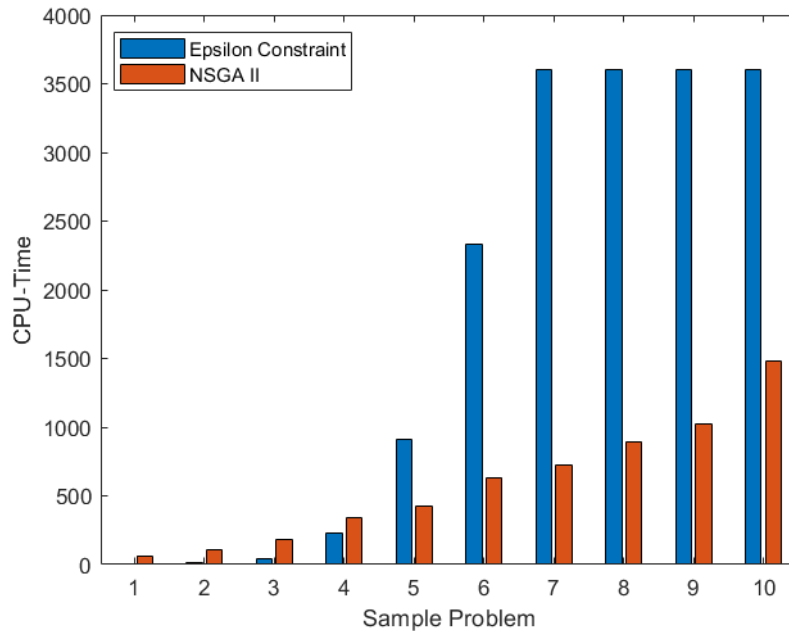
Fig. 3. Final comparison of two algorithms in sample Problems

Generally, according to the obtained means of index values, it can be seen that the NSGA II algorithm in low and medium scales (problems 1 to 6) has worked very close to Epsilon Constraint and optimal solution, as in problems 5 and 6 the performance diagram of the NSGA II algorithm is fully consistent with the exact solution. NSGA II performed better than Epsilon Constraint in this dimension because precision solution in high dimensions loses its efficiency. But, what is important is that the output of each of these algorithms is reliable and the resulting answers are valid. Therefore, it can be used as a suitable solving method for large-scale problems. Also, Table (5) shows the time of solving the different categories of the problems.

Table 5. Problem Solving Time (seconds)

Criterion Problem Method	CPU time	
	Epsilon Constraint	NSGA II
1	2.1	65.2
2	11.6	112.1
3	40.7	182.5
4	225.4	337.1
5	906.6	421.4
6	2331.7	632.6
7	> 3600	721.5
8	> 3600	896.7
9	> 3600	1019.4
10	> 3600	1481.2

According to Table (5), with increasing scales, the exact solution time has increased dramatically, to the extent that from the sample problem 7 onwards, the Epsilon method has failed to solve the problem accurately within the considered time limit. But the meta-heuristic algorithm is able to solve the problem in a more much shorter time. Therefore, the NSGA II algorithm has acceptable performance in a good solution time. This interpretation can also be seen in Figure (4).

**Fig. 4. Solving time of two algorithms**

5. Concluding remarks

In this paper, a multi-level supply chain is developed that includes production, recycling, inspection, distribution, customer and waste disposal centers, a green planning model that makes the production, transportation, recycling and inspection of products green, and minimizes the environmental impacts of transportation of products, and on the other hand minimizes all supply chain costs. In this paper, to satisfy the environmental goal of the chain, we have used a method based on the product life cycle

called the Eco-indicator 99 method. One of the advantages of this method is cost savings and reduction of pollution as a result of using transportation equipment and common infrastructure, and by using supply chain greening methods, it tries to minimize environmental effects.

The proposed model was initially a nonlinear model that was later transformed into a linear programming model using operations research techniques and validated by a small-scale problem by MATLAB and GAMS software. On the other hand, because this problem has a lot of computational time complexity and real supply chain problems have 10 or 100 suppliers, manufacturers and customers. To solve such problems, meta-heuristics methods are used that find near-optimal solutions in a much shorter time. In this research, NSGA II algorithm is one of the multi-objective optimization algorithms. These algorithms were compared with Epsilon Constraint method in solving large-scale problem solving.

References

- [1] Zhang, D., Zou, F., Li, S., & Zhou, L. (2017). Green supply chain network design with economies of scale and environmental concerns. *Journal of Advanced Transportation*, 2017. <https://doi.org/10.1155/2017/6350562>
- [2] Ghahremani Nahr, J., Pasandideh, S. H. R., & Niaki, S. T. A. (2020). A robust optimization approach for multi-objective, multi-product, multi-period, closed-loop green supply chain network designs under uncertainty and discount. *Journal of industrial and production engineering*, 37(1), 1-22. <https://doi.org/10.1080/21681015.2017.1421591>
- [3] Ghahremani-Nahr, J., Nozari, H., & Bathaee, M. (2021). Robust Box Approach for Blood Supply Chain Network Design under Uncertainty: Hybrid Moth-Flame Optimization and Genetic Algorithm. *International Journal of Innovation in Engineering*, 1(2), 40-62. <https://doi.org/10.52547/ijie.1.2.40>
- [4] Waltho, C., Elhedhli, S., & Gzara, F. (2019). Green supply chain network design: A review focused on policy adoption and emission quantification. *International Journal of Production Economics*, 208, 305-318. <https://doi.org/10.1016/j.ijpe.2018.12.003>
- [5] Ghahremani Nahr, J., Kian, R., & Rezazadeh, H. (2018). A modified priority-based encoding for design of a closed-loop supply chain network using a discrete league championship algorithm. *Mathematical problems in engineering*, 2018. <https://doi.org/10.1155/2018/8163927>
- [6] Ghahremani-Nahr, J., Nozari, H., & Najafi, S. E. (2020). Design a green closed loop supply chain network by considering discount under uncertainty. *Journal of Applied Research on Industrial Engineering*, 7(3), 238-266. DOI: [10.22105/jarie.2020.251240.1198](https://doi.org/10.22105/jarie.2020.251240.1198)
- [7] Watt, M. J., Clark, A. K., Selth, L. A., Haynes, V. R., Lister, N., Rebello, R., ... & Taylor, R. A. (2019). Suppressing fatty acid uptake has therapeutic effects in preclinical models of prostate cancer. *Science translational medicine*, 11(478). DOI: [10.1126/scitranslmed.aau5758](https://doi.org/10.1126/scitranslmed.aau5758)
- [8] Tosarkani, B. M., & Amin, S. H. (2019). An environmental optimization model to configure a hybrid forward and reverse supply chain network under uncertainty. *Computers & Chemical Engineering*, 121, 540-555. <https://doi.org/10.1016/j.compchemeng.2018.11.014>
- [9] Ghahremani Nahr, J. (2020). Improvement the efficiency and efficiency of the closed loop supply chain: Whale optimization algorithm and novel priority-based encoding approach. *Journal of Decisions and Operations Research*, 4(4), 299-315. DOI: [10.22105/dmor.2020.206930.1132](https://doi.org/10.22105/dmor.2020.206930.1132)

- [10] Nahr, J. G., Nozari, H., & Sadeghi, M. E. (2021). Green supply chain based on artificial intelligence of things (AIoT). *International Journal of Innovation in Management, Economics and Social Sciences*, 1(2), 56-63. <https://doi.org/10.52547/ijimes.1.2.56>
- [11] Zahran, S. K., Jaber, M. Y., & Zanoni, S. (2017). Comparing different coordination scenarios in a three-level supply chain system. *International Journal of Production Research*, 55(14), 4068-4088. <https://doi.org/10.1080/00207543.2016.1249431>
- [12] Yao, J., Shi, H., & Liu, C. (2020). Optimising the configuration of green supply chains under mass personalisation. *International Journal of Production Research*, 58(24), 7420-7438. <https://doi.org/10.1080/00207543.2020.1723814>
- [13] Tsao, Y. C., Thanh, V. V., Lu, J. C., & Yu, V. (2018). Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming. *Journal of Cleaner Production*, 174, 1550-1565. <https://doi.org/10.1016/j.jclepro.2017.10.272>
- [14] Zhen, L., Huang, L., & Wang, W. (2019). Green and sustainable closed-loop supply chain network design under uncertainty. *Journal of Cleaner Production*, 227, 1195-1209. <https://doi.org/10.1016/j.jclepro.2019.04.098>
- [15] Khodadadian, D., RADFAR, R., & TOLOIE, E. A. (2019). Designing a mathematical model for the multi-product green supply chain of automobile industry under uncertainty
- [16] Ghomi-Avili, M., Tavakkoli-Moghaddam, R., Jalali Naeini, S. G., & Jabbarzadeh, A. (2021). Competitive green supply chain network design model considering inventory decisions under uncertainty: a real case of a filter company. *International Journal of Production Research*, 59(14), 4248-4267. <https://doi.org/10.1080/00207543.2020.1760391>
- [17] Eskandari-Khanghahi, M., Tavakkoli-Moghaddam, R., Taleizadeh, A. A., & Amin, S. H. (2018). Designing and optimizing a sustainable supply chain network for a blood platelet bank under uncertainty. *Engineering Applications of Artificial Intelligence*, 71, 236-250. <https://doi.org/10.1016/j.engappai.2018.03.004>
- [18] Guo, C., Liu, X., Jin, M., & Lv, Z. (2016). The research on optimization of auto supply chain network robust model under macroeconomic fluctuations. *Chaos, Solitons & Fractals*, 89, 105-114. <https://doi.org/10.1016/j.chaos.2015.10.008>
- [19] Ghahremani Nahr, J., Ghodrathnama, A., IzadBakhah, H. R., & Tavakkoli Moghaddam, R. (2019). Design of multi-objective multi-product multi period green supply chain network with considering discount under uncertainty. *Journal of Industrial Engineering Research in Production Systems*, 6(13), 119-137. DOI: [10.22084/ier.2017.8877.1421](https://doi.org/10.22084/ier.2017.8877.1421)
- [20] Perez Loaiza, R. E., Olivares-Benitez, E., Miranda Gonzalez, P. A., Guerrero Campanur, A., & Martinez Flores, J. L. (2017). Supply chain network design with efficiency, location, and inventory policy using a multiobjective evolutionary algorithm. *International Transactions in Operational Research*, 24(1-2), 251-275. <https://doi.org/10.1111/itor.12287>
- [21] Zhao, K., Zuo, Z., & Blackhurst, J. V. (2019). Modelling supply chain adaptation for disruptions: An empirically grounded complex adaptive systems approach. *Journal of Operations Management*, 65(2), 190-212. <https://doi.org/10.1002/joom.1009>
- [22] Pishvaei, M. S., Rabbani, M., & Torabi, S. A. (2011). A robust optimization approach to closed-loop supply chain network design under uncertainty. *Applied mathematical modelling*, 35(2), 637-649. <https://doi.org/10.1016/j.apm.2010.07.013>

- [23] Melo, M. T., Nickel, S., & Saldanha-da-Gama, F. (2012). A tabu search heuristic for redesigning a multi-echelon supply chain network over a planning horizon. *International Journal of Production Economics*, 136(1), 218-230. <https://doi.org/10.1016/j.ijpe.2011.11.022>
- [24] Pishvae, M. S., & Razmi, J. (2012). Environmental supply chain network design using multi-objective fuzzy mathematical programming. *Applied Mathematical Modelling*, 36(8), 3433-3446. <https://doi.org/10.1016/j.apm.2011.10.007>
- [25] Das, K., & Posinasetti, N. R. (2015). Addressing environmental concerns in closed loop supply chain design and planning. *International Journal of Production Economics*, 163, 34-47. <https://doi.org/10.1016/j.ijpe.2015.02.012>
- [26] Fakhrazad, M. B., & Goodarzian, F. (2019). A fuzzy multi-objective programming approach to develop a green closed-loop supply chain network design problem under uncertainty: modifications of imperialist competitive algorithm. *RAIRO: Recherche Opérationnelle*, 53.
- [27] Khalilzadeh, M., & Derikvand, H. (2018). A multi-objective supplier selection model for green supply chain network under uncertainty. *Journal of Modelling in Management*.



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