F O U N D A T I O N S O F C O M P U T I N G A N D D E C I S I O N S C I E N C E S
Vol. 47 (2022) No. 2
ISSN 0867-6356
DOI: 10.2478/fcds-2022-0007 e-ISSN 2300-3405

sciendo

Developing a Mathematical Model for a Green Closed-Loop Supply Chain with a Multi-Objective Gray Wolf Optimization Algorithm

Mehdi Dastani[1], Sayyed Mohammad Reza Davoodi [2]*,
Mehdi Karbassian[3], Shahram Moeini [4]

Abstract. Intense competition in today's market and quick change in customer preferences, along with the rapid development of technology and globalization, have forced companies to work as members of a supply chain instead of individual companies. The success of the supply chain depends on the integration and coordination of all its institutions to form an efficient network structure. An efficient network leads to cost savings throughout the supply chain and helps it respond to customer needs faster. Accordingly, and with respect to the importance of the supply chain, in this study a developed mathematical model for the design of a green closed-loop supply chain is presented. In this mathematical model, the economic and environmental objectives are simultaneously optimized. In order to tackle this mathematical model, two methods of epsilon constraint and multi-objective gray wolf optimization (MOGWO) algorithm have been applied. The results of comparisons between the two mentioned methods show that MOGWO reduce the average solving time from about 1300 seconds to 88 seconds. In the last step of this research, in order to show the application of the proposed mathematical model and the method of solving the research problem, it was implemented in the supply chain of Dalan Kouh diary product and the Pareto optimal solutions were analyzed.

Keywords: green closed-loop supply chain, epsilon constraint, multi-objective Gay wolf algorithm, Pareto boundary.

[1] Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran
[2]Dehaghan branch, Islamic Azad University,Dehaghan, Iran, Email: smrdavoodi@ut.ac.ir
[3] Malek Ashtar University of Technology, Isfahan, Iran
[4] University of Isfahan, Isfahan, Iran

1. Introduction

The green supply chain aims to alleviate environmental damage and control air, water, and waste pollution by adopting green approaches in business operations. Certainly, the fundamental principle behind the green idea is to improve environmental sustainability. However, companies assume the green notion as killing two enemies with a bullet [48]. The main reason is that the green supply chain is able to decrease environmental pollution and production expenses. Moreover, it is able to provoke economic development, produce a competitive benefit regarding positive image, better customer satisfaction, and supply a more suitable chance to export their products in pro-environmental nations [18].

Green supply chain management integrates supply chain management with environmental requirements at all stages to maximize productivity. Over the past two decades, environmental studies have become increasingly important in the world, increasing the number of laws and regulations in this matter and increasing public pressure have forced companies to pay special attention to the environment [45]. Therefore, there is increasing attention to the green supply chain and environmental issues in supply chain management have become more critical. Companies are forced to develop environmental issues to reduce their environmental impact. Also, the production of intended products at the factory level with the least contamination is known as a critical issue for the development and production of green parts. Production of the intended products at the factory level with the least pollution is known as a critical issue for the development and production of green parts [20].

Harmful or hazardous materials in the raw materials supplied by the supplier and the manufacturer can cause serious environmental impacts in the supply chain. For this reason, working with the right green suppliers is a very important issue, and integrating environmental issues into supplier development activities for long-term competition and the processes of central companies and their supply chains becomes a necessity. Tarokh and Gouke (2010) investigate the supply chain as including the coordination and integration of key business activities from the purchase of raw materials to the distribution of final products to customers, which requires the process of supply chain planning. According to Hassani (2010) [27], in decision-making processes in the supply chain, the creation of the main factor that may affect the effectiveness of the configuration and coordination throughout the chain is uncertainty [22; 23]. In fact, attention to optimization in the supply chain under uncertainty conditions will reduce costs and improve quality, and thus an advantage and a competitive position will be achieved.

According to Aghaahmadi and Mahouchi (2017) [1], empirical research has shown that the integration of the supply chain offers better business and operational performance. Senior executives of organizations are always looking for a solution to the problems of different organizational units. Meanwhile, selecting the right supplier has become one of the most fundamental issues in the supply chain of organizations. The matter of choice of supplier involves analyzing and measuring the performance of a set of suppliers in order to rank them down with the aim of improving the competitive situation in the entire supply system. In fact, choosing the right supplier is the key to achieving the desired quality rather than the appropriate price, enough level of technical support and the desirable level of service.

2. Research background

Recently, the concept of the green supply chain has attracted significant attention from the researchers. Generally, a supply chain is a network of suppliers, manufacturers, distributors, and retailers through which raw materials are transported, manufactured and eventually delivered to consumers [47]. Therefore, a green supply chain involves a complicated flow of materials, products, and information throughout the supply chain, which simultaneously seeks to increase quality, reduce costs and environmental pollution. Organizations have been improving their supply chains due to increased competition in global markets [24; 45]. In reviewing the research in this field, the following can be mentioned in the group of the most important research in this field Ghorbanpour and Shamsodin (2016) [17] investigated the design of the structural model of green supply chain management practices using a facial interpretive structural modeling approach. Gandhi (2018) [15] has monitored the components of the green supply chain performance in India's automotive industry. Akbarijovkar et al. (2016) developed a full closed-loop chain network under the conditions of the uncertainty of demand and product return.

Beheshtinia (2017) [7] have explored a model for integrating the vehicle routing problem in a supply chain with the problem of assigning orders to suppliers and determining the sequence of production using genetic algorithms. Ahmadinezhad et al. (2018) [2] in an article entitled Choosing a Business Strategy for Green Supply Chain Management, utilizes the network analysis process to identify and rank the green supply chain management strategies using the ANP method. Miranda et al. (2017) [33] identified the most important challenges in supply chain network design, including multiple levels and multiple constraints. This strategy comes from the field of economic and functional considerations, and in its evolution, itself includes the environmental and social aspects. Saffar et al. (2017) [41] and Goli & Malmir (2020) [20] investigated the problem of designing a green closed-loop supply chain considering operational risks under uncertainty conditions and solving them with a multi-objective evolutionary algorithm (MODE). Golpira et al. (2017) studied the multi-level multi-objective green supply chain network design by considering risk vendor retailors under uncertainty conditions and Fazlikhalaf et al. (2017) [14] presented a robust randomization model to design a green closed loop supply chain network. Nurjanni et al. (2017) [37] proposed a new green supply chain design approach to counter conflicts between environmental and financial issues in order to reduce the negative impacts on the environment caused by an increase in industrialization levels.

Zhou and Wei (2017) presented a non-linear integer model for locating and determining inventory and selling price in a closed-loop chain. In order to solve this model, an inventory method based on ordering inventory system and ordering process have been designed and implemented. Raad and Nahavandi (2018) presented an integrated multi-objective model for designing a closed-loop green supply chain considering product quality and discount in the chain. The objectives of this model include reducing costs, reducing environmental pollution and increasing customer satisfaction. Mortazavi and Seyfbarghi (2018) [34] with designing and two-dimensional modeling, have studied allocation problems in a green supply chain, by considering the transportation and CO2 emission system, with the constraint of minimizing the total cost of the network and CO2 emission simultaneously. Liang and Kouesta (2018) [31] have studied the supply chain of fuel transportation, they introduced the reduction of energy costs and greenhouse gases as the main constraints of

this chain and improved them. This research has been implemented in Japan and is the ideal solution that creates a balance between energy costs and environmental pollution.

Zhang and Yang (2018) developed a multi-objective model for designing a supply chain network that could balance the overall cost and environmental performance in the supply chain network of two green channel. In this research, transport mode is considered as a decision variable. Considering the complexity of such a network, a multi-objective particle Swarm optimization algorithm (MOPSO) has been used to counteract this problem. Pasuki et al. (2019) [38] developed a new mathematical model for designing the green and pure supply chain. The study, which has been used in the automotive industry, seeks to reduce environmental pollution, use of maximum capacity in factories, and reduce supply chain costs. Nouridarian and Taleezadeh (2018) [36] have developed the inventory and production model in the three-level supply chain in order to reduce supply chain costs using an inventory control optimization policy. In this study, the Stackelberg approach has been used to solve the proposed models.

The role of the circular economy in the supply chain has more interesting for researchers since 2019. Alonso et al. (2019) investigate the effect of the circular economy in the apparel industry. They concluded that along with the supply chain different circles are therefore created to reduce, reuse, recycle, remanufacture, recover and redesign material during the life cycle of a product. Forooque et al. (2019) provided a comprehensive literature review in the field of the circular supply chain. It has been shown that this research conducts a structured literature review of 261 research articles on the current state of circular supply chain research. Based on the review results, the researchers call for further studies in the following directions that are important but received little or no attention: design for circularity, procurement and CSCM, biodegradable packaging, circular supply chain collaboration and coordination, drivers and barriers of circular supply chain, circular consumption, product liabilities and producer's responsibility, and technologies [12].

Howard et al. (2019) [28] presented a framework for developing circular economy indicators that link to the core goals, principles and building blocks of a circular economy. To do this they utilized the Ellen MacArthur Foundation butterfly model as a coherent systems overview of key material stocks and flows, and representation of relationships between inputs, outputs, recovery processes, emissions, energy and value loops in physical and financial measures which constitute the circular supply chain. Based on nine multinational organizations and four cases of leading companies engaged with CE activity, we address the types of indicators being used and make recommendations for indicators to reflect key goals and principles of the circular economy [26].

The research gap includes considering simultaneous distribution centers, allocation of customers to distribution centers, and the determination of the distribution system of the supply chain and attention to environmental pollution simultaneously. This study investigates a novel supply chain network design emphasizing the circular supply chain. Accordingly, a mathematical model with two essential objectives is proposed. The first objective is to improve the economic aspect of the supply chain and the second one is about the environmental effect in the supply chain. The multi-objective gray wolf optimization algorithm will be applied to optimize this problem, which is one of the newest multi-objective solution methods.

3. Research Methodology

3.1. Proposed mathematical model

In this research, we investigate the supply chain of dairy products in the field of the circular supply chain. As an environmental effect and ecumenical effect are the most important factors in the circular supply chain, in this study, these two factors are considered as independent objectives. In this supply chain, milk and other essential raw materials are supplied from different suppliers. Also, the excess need is supplied from the milk collection station, which is an intermediary. After production, products are sent to different distributors and they store them after inspection and distribute at appropriate times between customers. The distributor has the ability to store goods and deliver in the coming periods. This condition causes a percentage of products in the distributor's warehouse to be corrupted and needs to be returned to the factory. The manufacturing factory processes the percentage of returned products and returns to the distribution and sale cycle. Other returned products are considered as waste products and are disposed.

Other assumptions of the mathematical model are as follows:

• The supply chain has 4 main echelons, including supplier, manufacturer, distributor, and customers.

• As the milk is a necessary raw material, a milk collection center is considered to complete the supply chain needs.

• Different transport systems are considered each echelon of the supply chain with fixed and variable costs.

• Only one transportation system can be used between each supplier and distributor, as well as between each distributor and customer.

• The supply chain is required to meet the total demand of customers.

• There are several potential centers for the establishment of distribution centers, one or more of which must be established.

• The number of centers to be established is not known beforehand, but the mathematical model should provide the best possible scenarios, given the amount of demand and construction and posting costs.

Indexes:

S:	The supplier fixed location index (s = 1, 2,…, S)
I:	factory fixed locations index (i = 1, 2, ..., I)
J:	The index of potential locations for distribution centers (j = 1,2, ..., J)
C:	customers fixed location index (c = 1,2, ..., C)
P:	Product index (p = 1,2, ..., P)
R:	Raw material index (r = 1,2, ..., R)
L:	transportation systems index (l = 1,2, ..., L)
T:	Time period index (t = 1,2, ..., T)

Parameters

D_{cp}^{t}	Customer c demand for product p in period t
SC_{sr}^{t}	The cost of purchasing unit of raw material r from supplier s in period t
$\dot{M}C_{ip}^{t}$	Unit of cost of production of product p at factory i in period t
IC_{jp}^{t}	The cost of each inspection and recycling unit product p at the distribution center j in period t
HC_{jP}^{t}	The unit of maintenance cost product p at distribution center j in period t
FY_{j}^{t}	The fixed cost of setting up the distribution center j in period t
CS_{sr}^{t}	Supplier's capacity s for supplier r during period t
CX_{i}^{t}	Production capacity at factory i in period t
CY_{j}^{t}	The capacity of the distribution center j in period t
CSI_{sir}^{t}	Unit of cost of transfer of raw material r from supplier s to factory i in period t
CIJ_{ijpl}^{t}	Unit of cost of product transfer p from factory i to distribution center j in period t with transport system l
CJC_{jcpl}^{t}	Unit of cost of product transfer p from distribution center j to customer c with transport system l during period t

CJI_{jipl}^{t}	Unit of transfer cost of product p from distribution center j to factory i in period t with transport system l
CTR_{l}^{t}	The fixed cost of transporting l during the period t
ESI_{sir}^{t}	The Co2 pollution unit resulting from the transfer of raw material r from the supplier s to the factory i during period t
EIJ_{ijpl}^{t}	Co2 pollution unit resulting from the transfer of product p from factory i to distribution center j in period t with transport system l
EJI_{jipl}^{t}	Co2 pollution unit resulting from the transfer of product p from distribution center j to factory i during period t with transport system l
EJC_{jcpl}^{t}	Co2 pollution unit resulting from the transfer of product p from distribution center j to customer c with transport system l during period t
$\dot{EC}_{ip}^{t}$ Co2	pollution unit from production of product p in factory i in period t
n_{rp}	Coefficient of consumption of raw material r in product p
m_{p}	Capacity utilization rate in production of product p
R_{p}	Return percent of product p to factory
Rp_{p}	The percentage of product processing p from the returned products to the factory
BM	A very large number

Decision variables

QSI_{sir}^{t}	The amount of raw material r sent from the supplier s to factory i in period t
$QS0_{ir}^{t}$	The amount of raw material r sent from the supply station to the factory i during period t
QI_{ip}^{t}	The amount of product p produced in factory i in period t
QIJ_{ijpl}^{t}	The distribution center j with the transport system l in period t
INV_{jp}^{t}	The product inventory p at the distribution center j at the end of period t
QJC_{jcpl}^{t}	The amount of product p transferred from the distribution center j to the customer c with the transport system l during the period t
QJI_{jipl}^{t}	The amount of the product p sent from the distribution center j to the factory i with the transport system l during the period t
Y_{J}^{t}	The binary variable is equal to 1 if at the j point in period t, the distribution center is launched
A_{ijl}^{t}	The binary variable is equal to 1 if the transport system l connects the factory i and the distribution center j in period t
B_{jcl}^{t}	The binary variable is equal to 1 if the transport system l connects the distribution center j to client c in period t.

Mathematical model equations

$$Min\ Z1 = \sum_{t}\sum_{j} FY_{i}^{t}(Y_{j}^{t}) +$$
$$+\sum_{t}\sum_{s}\sum_{i}\sum_{r}(QSI_{sir}^{t} + QS0_{ir}^{t})\ SC_{sr}^{t}$$
$$+\sum_{i}\sum_{p}\sum_{t} QI_{ip}^{t}\ MC_{ip}^{t}$$
$$+\sum_{t}\sum_{c}\sum_{j}\sum_{p}\sum_{l} QJC_{jcpl}^{t}\ IC_{jp}^{t}$$
$$+\sum_{t}\sum_{j}\sum_{p} INV_{jp}^{t} HC_{p}^{t}$$
$$+\sum_{t}\sum_{s}\sum_{i}\sum_{r} QSI_{sir}^{t} CSI_{sir}^{t}$$
$$+\sum_{t}\sum_{i}\sum_{j}\sum_{p}\sum_{l} QIJ_{ijpl}^{t}\ CIJ_{ijpl}^{t}$$
$$+\sum_{t}\sum_{j}\sum_{c}\sum_{p}\sum_{l} QJC_{jcpl}^{t}\ CJC_{jcpl}^{t} +$$

$$\sum_t \sum_i \sum_j \sum_p \sum_l QJI_{jipl}^t \, CJI_{jipl}^t + \sum_t \sum_j \sum_i \sum_l A_{ijl}^t \, CTR_l^t + \sum_t \sum_j \sum_c \sum_l B_{jcl}^t \, CTR_l^t \quad (1)$$

$$Min\ Z2 = \sum_i \sum_p \sum_t QI_{ip}^t \, EC_{ip}^t + \sum_t \sum_s \sum_i \sum_r QSI_{sir}^t ESI_{sir}^t + \sum_t \sum_i \sum_j \sum_p \sum_l QIJ_{ijpl}^t \, EIJ_{ijpl}^t + \sum_t \sum_j \sum_c \sum_p \sum_l QJC_{jcpl}^t \, EJC_{jcpl}^t + \sum_t \sum_i \sum_j \sum_p \sum_l QJI_{jipl}^t \, EJI_{jipl}^t \quad (2)$$

Subject to

$$\sum_{\mathrm{j}} \sum_{\mathrm{P}} \sum_{\mathrm{l}} \mathrm{n_{rp}} \mathrm{QIJ_{ijpl}^t} = \sum_{\mathrm{s}} QSI_{sir}^t \quad , \forall \mathrm{i, r, t} \quad (3)$$

$$INV_{jp}^{t-1} + \sum_{\mathrm{i}} \sum_{l} \mathrm{QIJ_{ijpl}^t} = INV_{jp}^t + \sum_{\mathrm{c}} \sum_{l} QJC_{jcpl}^t + \sum_{\mathrm{i}} \sum_{l} QJI_{jipl}^t \quad , \forall j, p, t \quad (4)$$

$$\sum_{\mathrm{j}} \sum_{l} QJC_{jcpl}^t = D_{cp}^t, \quad \forall c, p, t \quad (5)$$

$$\sum_{\mathrm{i}} QSI_{sir}^t \leq CS_{sr}^t \ , \qquad \forall s \ , r, t \quad (6)$$

$$\sum_{\mathrm{j}} \sum_{p} \sum_{l} m_p QIJ_{ijpl}^t \leq CX_i^t \ , \forall i, t \quad (7)$$

$$\sum_{\mathrm{p}} \mathrm{INV_{jp}^t} + \sum_{\mathrm{c}} \sum_{\mathrm{p}} \sum_{\mathrm{l}} \mathrm{QJC_{jcpl}^t} \leq C\mathrm{Y_j^t Y_j^t}, \qquad \forall \mathrm{j, t} \quad (8)$$

$$\sum_{\mathrm{l}} A_{ijl}^t \leq 1 \quad , \quad \forall \mathrm{i, j, t} \quad (9)$$

$$\sum_{\mathrm{l}} B_{jcl}^t \leq 1 \quad , \quad \forall \mathrm{j, c, t} \quad (10)$$

$$\mathrm{A_{ijl}^t} \leq \sum_{\mathrm{p}} QIJ_{ijpl}^t \ , \qquad \forall i, j, l, t \quad (11)$$

$$\mathrm{B}_{\mathrm{jcl}}^{\mathrm{t}} \leq \sum_{\mathrm{p}} QJC_{jcpl}^{t} \quad , \qquad \forall j, c, l, t \tag{12}$$

$$\sum_{\mathrm{p}} QIJ_{ijpl}^{t} + QJI_{jipl}^{t} \leq BM * A_{ijl}^{t} \quad , \qquad \forall i, j, l, t \tag{13}$$

$$\sum_{\mathrm{p}} QJC_{jcp}^{t} \leq BM * B_{jcl}^{t} \quad , \qquad \forall j, c, l, t \tag{14}$$

$$\sum_{i} QJI_{jipl}^{t} = R_{p} * \mathrm{INV}_{\mathrm{jp}}^{t} \quad , \qquad \forall j, p, l, t \tag{15}$$

$$\sum_{j} QIJ_{ijpl}^{t} = QI_{ip}^{t} + Rp_{p} * \sum_{j} QJI_{jipl}^{t} \quad , \ \forall i, p, l, t \tag{16}$$

Eq. (1) expresses the total costs of each chain period. These costs include the fixed costs of setting up distribution centers and purchasing from suppliers, production costs, operating costs at distribution centers, inventory costs at distribution centers, and transmission costs by various transportation systems in the supply chain. Eq. (2) also minimizes the total amount of Co2 released from product production, transfers from supplier to the factory, transfers from the factory to distribution centers and transfers from distribution centers to customers.

Eq. (3) shows that the amount of raw material imported to each factory in each period is equal to the output of that factory in the same period. Eq. (4) ensures that for each of the products in each of the periods, the amount entered into each distribution center as well as the remaining inventory of the previous period is equal to the amount sent to customers and the rest of the inventory at the end of the period. This equation is known as the balance of inventory. Eq. (5) states that for each product and in each period, the available amount in each distribution center must be able to meet the demand for that product. Eq. (6) ensures that the amount of each raw material sent from suppliers does not exceed their capacity. Eq. (7) states the constraint of the capacity of materials in the factories as suppliers. Eq. (8) states that the remaining inventory at each distribution center should not exceed their capacity. Eq. (9) and Eq. (10) state that only one transport system can be used in each of the chain members. Eq. (1) and Eq. (12) point out that the transportation system is used by members of the chain that send each other. Eq. (13) and Eq. (14) state that members of a chain that does not have a connection no goods are also sent. Eq. (15) determines the amount of returned goods as a percentage of the distributor's inventory. Eq. (16) points out that the amount of goods sent from the factory to the distribution centers is equal to the amount produced at the factory and is a percentage of returned products that are being redeveloped.

3.2. Methods for solving the proposed mathematical model

Using novel meta-heuristic algorithm in optimizing NP-HARD problems are addressed and suggested in different researches in the field of optimization [46; 9; 19; 24; 42]. Considering that the designed mathematical model is a multi-objective model, multi-objective optimization methods should be used to solve this model. In this regard, the Epsilon Constraint Method and MOGWO are used.

3.3. Multi-objective gray wolf optimization

The Gray Wolf Optimization (GWO) algorithm, is a nature-inspired meta-heuristic algorithm that imitates 0the behavior of gray wolves and the hierarchy of leadership and their hunting method. The GWO algorithm is presented by Mirjalili and his colleagues in 2014 based on their collective hunt. In a way that alpha wolf, the ruling wolf is also called in the group, because his orders must be followed by the group. Alphas are basically responsible for deciding about hunting, sleeping place, movement time, and the like.

Gray wolves circle the bait during hunting. For mathematical modeling of circling behavior, equations 17 and 18 is proposed.

$$\vec{D} = \left|\vec{C}.\overrightarrow{X_P}(t) - \vec{X}(t)\right| \tag{17}$$

$$\vec{X}(t+1) = X_P(t) - \vec{A}.\vec{D} \tag{18}$$

Where t indicates the repetition of flow, A and C is the vector coefficient, $\overrightarrow{X}_P$ the vector of the hunting position, and X represents the position vector of a gray wolf. The vectors A and C are calculated according to equations 19 and 20.

$$\vec{A} = 2\vec{a}.\overrightarrow{r_1} - \vec{a} \tag{19}$$

$$\vec{C} = 2.\overrightarrow{r_2} \tag{20}$$

whre the $\vec{a}$ elements are linearly reduced from 2 to 0 under the path of repetitions, and random vectors are in the interval [0, 1].

we save the first three best solutions gained here and force other search factors (omegas) to update their position according to the position of the best search factors. This operation is carried out in accordance with Eqs. (21)-(23).

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\overrightarrow{X_\alpha} - \vec{X}\right|, \qquad \overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\overrightarrow{X_\beta} - \vec{X}\right|, \qquad \overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\overrightarrow{X_\delta} - \vec{X}\right|, \tag{21}$$

$$\vec{X}_1 = \overrightarrow{X_\alpha} - \overrightarrow{A_1}.\left(\vec{D}_\alpha\right), \qquad \vec{X}_2 = \overrightarrow{X_\beta} - \overrightarrow{A_1}.\left(\vec{D}_\beta\right), \qquad \vec{X}_3 = \overrightarrow{X_\delta} - \overrightarrow{A_1}.\left(\vec{D}_\delta\right), \tag{22}$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \tag{23}$$

In summary, in the GWO algorithm, the searching process begins by creating a random population of gray wolves (candidate solutions). In MOGWO, the total framework is similar to GWO. However, in each iteration of MOGWO, the non-dominated solutions are specified and updated. Finally, the set of non-dominated solutions are reported.

3.4. Case study

The statistical population of this study is the country's dairy industry, and as a sample, Dalan Kouh Company has been selected to implement the proposed model of research. After presenting the developed mathematical model as well as its optimization methods, its implementation is discussed in a real case study.

The company is located in Iran, Isfahan, and owns 500 livestock. The factory has started working with a total area of 10,000 square meters, with a capacity of 40,000 tons per year in a production line, with the latest technology globally, and with full automation and high precision, using experienced and expert staff. The cows in this company are from the best

breed of purebred cows (Holstein), which made the calves born from blood purity even higher from the very beginning. The company has also received ISO14001 certifications.

4. Numerical results

4.1. Designing the experiments for the parameters of MOGWO algorithm

In order to design experiments in the MOGWO algorithm, the first three levels are defined for its parameters, and then the pre-defined experiments in this algorithm are executed. The proposed values for the parameters of this algorithm are according to Table 1.

Table 1. Parameters and their levels for MOGWO algorithm

Algorithm	parameter	Values in every level		
		Level 1	level 2	level 3
MOGWO	Maximum number of Iterations (Max_iter)	100	200	300
	Number of search agent (N_S)	10	20	50
	Change position rate (PR)	0.1	0.2	0.3

Then, with the L9 Taguchi scheme, different experiments are created, and for each of them MOGWO algorithm is implemented, and in MINITAB software S / N diagrams are presented in Fig. 1. Now, based on the output presented in the diagram above, the best value of each parameter is specified, and the other examples are implemented with these values of algorithm parameters. In Table 2, the optimal parameters are presented.

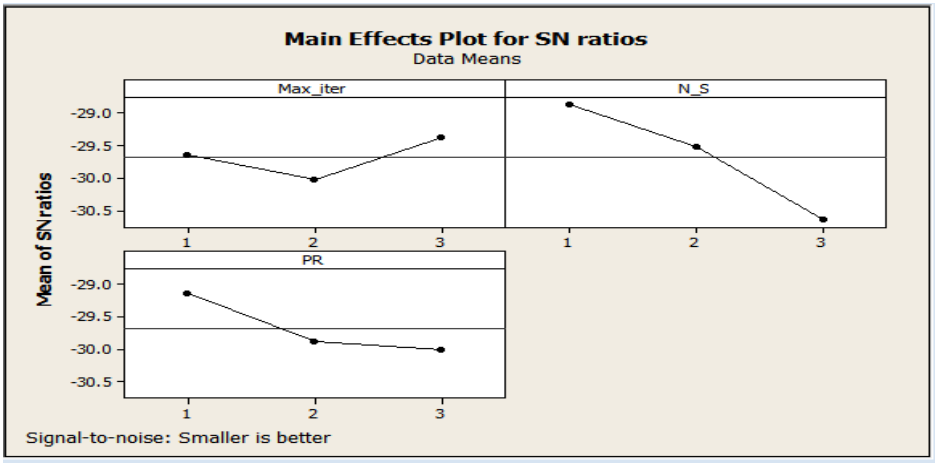

Figure 1. Mini-tab output for Taguchi method in MOGWO algorithm

Table 2. The optimal value of the variables in MOGWO

Algorithm	parameter	Optimal value
MOGWO	Maximum number of Iterations (Max iter)	200
	Number of search agent (N_S)	50
	Change position rate (PR)	0.3

4.2. Review the effectiveness of proposed solving methods

To compare the desired methods based on the reviewed indicators, 10 examples were produced in different dimensions. These examples are generated randomly. The information of these examples is described in Table 3. It should be noted that for each method of solving the time limit is considered 3600 seconds.

Table 3. Information on numerical examples

example	Number of suppliers	Number of factories	Number of production centers	Number of products	Number of raw materials	Number of transportation systems	Number of time periods
1	5	2	4	1	1	1	7
2	7	3	6	3	2	1	7
3	9	4	8	5	3	1	9
4	11	5	10	7	4	2	9
5	13	6	12	9	5	2	12
6	15	7	14	11	6	2	12
7	17	8	16	13	7	3	15
8	19	9	18	15	8	3	15
9	21	10	20	17	9	3	20
10	23	12	22	19	10	4	20

Then, both methods of solving the number of quality indices of the solution to the problem are calculated and reported in Tables 4 and Table 5.

Table 4. Epsilon constraint output for solved examples

Example	MID	Max Spread	SM	NPS	RAS	Spacing	CPU time
1	13.290	11.600	7.91	7	0.270	6.940	6.18
2	14.198	12.581	9.541326	10	0.353	9.558	12.95
3	15.261	14.930	10.06833	11	0.542	12.316	79.36
4	16.697	15.812	15.92292	11	0.723	17.144	425.85
5	17.244	16.501	19.61764	13	0.922	22.102	994.13
6	18.638	22.395	23.40268	15	1.547	22.914	1272.68
7	20.090	31.184	29.90024	17	2.112	33.732	2463.88
8	20.744	40.822	35.35586	19	3.072	35.858	3600.00
9	21.413	42.707	53.01155	19	3.660	48.813	3600.00
10	0.000	0.000	0	0	0.000	0.000	Not solved
Average	17.508	23.170	22.748	13.556	1.467	23.264	1383.892

Table 5. MOGWO output for solved examples

Example	MID	Max Spread	SNS	NPS	RAS	Spacing	CPU time
1	18.869	10.008	7.6622	6	0.345	7.065	13.95
2	18.750	18.431	10.0910	18	0.463	10.935	15.97
3	15.845	16.542	11.1755	26	0.652	14.679	32.97
4	18.627	22.470	22.0571	29	0.957	18.436	57.49
5	25.336	20.822	24.8277	30	1.040	27.163	73.85
6	19.234	30.336	23.6967	30	1.577	32.113	96.28
7	29.121	39.136	38.2629	37	2.427	45.893	127.49
8	30.477	49.408	52.1947	43	4.393	43.912	133.64
9	23.715	47.347	65.1100	50	4.110	53.015	157.96
10	23.690	56.216	60.4938	50	6.326	66.930	169.93
Average	22.366	31.071	31.5572	31.9	2.229	32.014	87.953

4.3. Review the solving methods based on the MID index

The average of this index for Epsilon constraint was 17.5 and for the MOGWO algorithm, it was 22.36. The results of this indicator indicate that MOGWO amount was higher in all examples. The reason for this is that the EPC method introduces the best possible values, so for the innovative method, the small distance with these values is equivalent to the quality of this method. The results based on MID index is presented in Fig. 2.

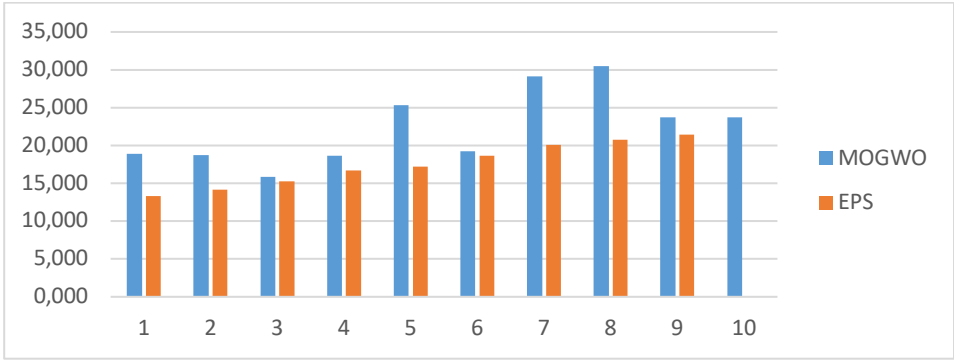

Figure 2. Comparing MOGWO and EPS on MID index

4.4. Review the solving methods based on the Max spread index

The average of this index for the Epsilon constraint was 23.1 and for the MOGWO algorithm was 31.07. As shown in Fig. 3, the EPC method has only been able to provide a better value than the MOGWO in the first example. In other examples, the MOGWO method provides a better value than this index, which indicates the effectiveness of this method in finding the solutions to the intended problem.

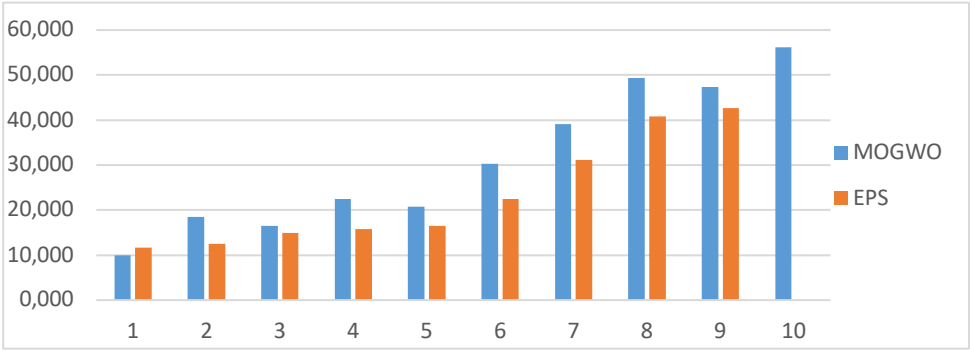

Figure 3. Comparing MOGWO and EPS on Max spread index

4.5. Review the solving methods based on the SNS index

The average of this index for Epsilon's limit was 22.7 and for the MOGWO algorithm was 31.55. Regarding the SNS index, like the Max spread, the MOGWO algorithm is also well-known for finding optimal solutions. By increasing the issue number, the superiority of the MOGWO method is seen in the SNS index. The results based on SNS index is presented in Fig. 4.

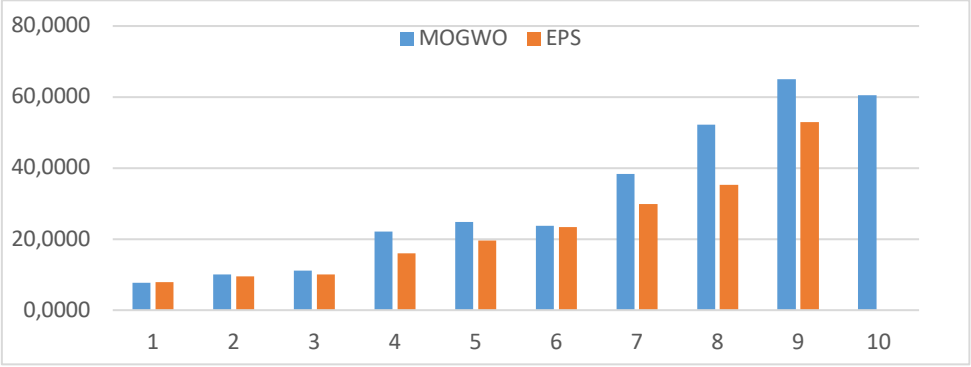

Figure 4. Comparing MOGWO and EPS on SNS index

4.6. Review the solving methods based on the NPS index

The average of this index for the Epsilon constraint was 13.55 and for the MOGWO algorithm was 31.90. The NPS index is one of the most important indicators that shows the superiority of the MOGWO algorithm over ECP. In the EPC method the ability to find various answers decreases due to constraints in the problem. But in the MOGWO algorithm, due to its random and intelligent search, it is possible to find more optimal solutions, which is why in the NPS index a much better performance of this algorithm is seen. The results based on NPS index is presented in Fig. 5.

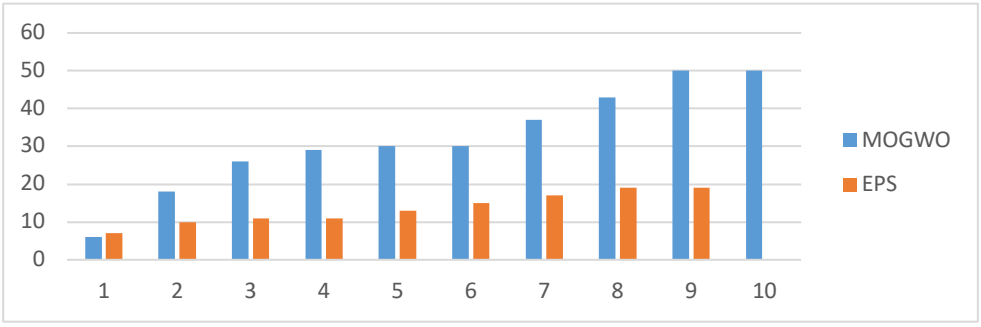

Figure 5. Comparing MOGWO and EPS on NPS index

4.7. Review the solving methods based on the RAS index

The average of this index for the Epsilon constraint was 1.46, and for the MOGWO algorithm was 2.22. As it can be seen in Fig. 6, the MOGWO algorithm offers more values in compare with EPC. This difference in a number of examples is little. The small difference between the MOGWO algorithm and the EPC method, which is on average about 0.6, indicates the ability of the MOGWO algorithm.

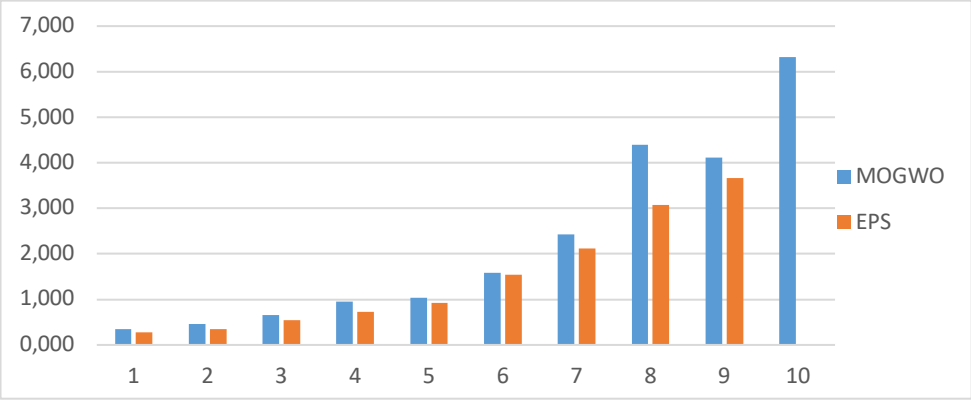

Figure 6. Comparing MOGWO and EPS on RAS index

4.8. Review the solving methods based on the Spacing index

The average of this index for the Epsilon constraint was 23.26 and for the MOGWO algorithm was 32.01. The analysis of this index is similar to the RAS index. The EPC method provides less values, and the MOGWO algorithm tries to provide a SNS close to this method. The above results show that this algorithm has been relatively successful in its attempt to be close to the ideal solution. The results based on Spacing index is presented in Fig. 7.

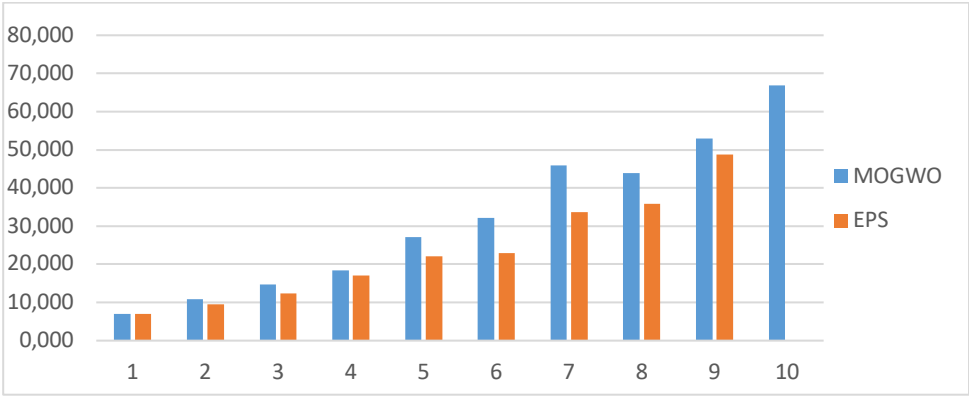

Figure 7. Comparing MOGWO and EPS on Spacng index

5.9. Review the solving methods based on time of solving

The reviews show that the Epsilon constraint has an average time of 1383.89 seconds. While this index for MOGWO is 87.95. Fig. 8 shows the comparison of the solving time of these two methods.

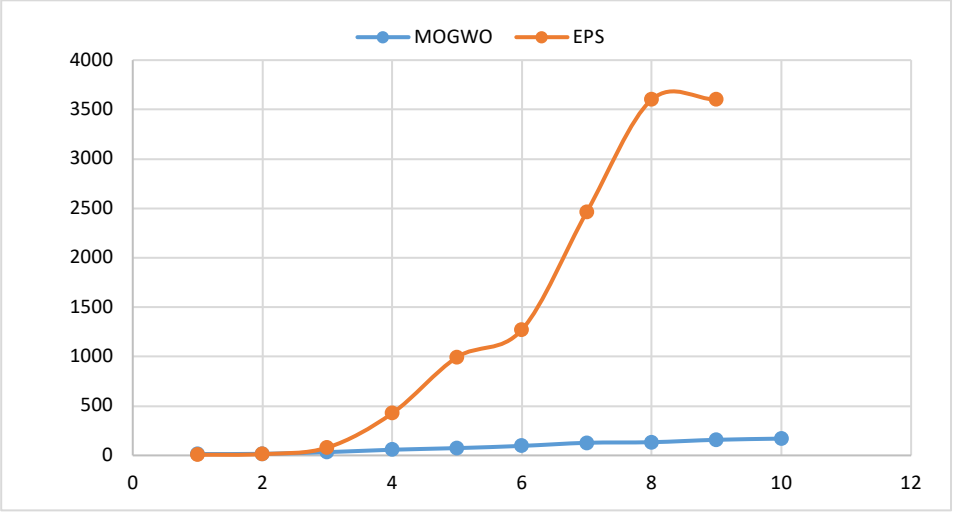

Figure 8. Comparison of solving time of two methods

As seen in the EPC method, the solving time has ascending trend with much slope. It has solved Problem 7 and 8 as long as possible and also did not have capabilities to solve problem 10. This is while the MOGWO algorithm has increased the solving time with a very small slope. In summary, after analyzing different indices, it is indicated that the MOGWO algorithm, with spending much less time than EPC, can provide very close outputs to optimal answers and even works better on some other indicators than EPC. This issue properly shows the ability of the MOGWO algorithm to solve the problem raised in this research.

4.10. Implementation on case study

In order to investigate the application of the proposed mathematical model, its solution is provided for the case study presented in Section. This supply chain has 5 feed supply centers in Isfahan, Bandar Abbas, Mazandaran, Chaharmahal Bakhtiari and Khuzestan provinces. In addition to the above, the chain also has a farm for supplying the feed. This feed is sent to the milk production center and then the produced milk is sent to the central factory in Fereidan. In order to cope with the changes in demand as well as the sudden need for milk, milk collection stations are also used. The factory produces 6 main products, including pasteurized milk, cheese, dough, yogurt, whey and cream. After production the product is sent to distribution centers in the provinces of Isfahan, Markazi, Chaharmahal Bakhtiari, Tehran, Khorasan Razavi, Kerman and Khuzestan. These centers are responsible for receiving and storing products and supplying demand for various cities in the country. For transportation inside the chain, three types of transportation systems used include Isuzu 6 tons, Isuzu 3 tons and Nissan. Defective products are detected in distribution centers and returned to the factory.

After collecting information about the parameters of the mathematical model, optimization of the desired supply chain structure is accomplished by solving the

mathematical model developed in this research. Initially, each goal is independently optimized in the GAMS software, which they obtained result presented in Table 6.

Table 6. results of optimizing the objectives of the mathematical model independently

Objective Functions	Amount of economic objective function (Rials)	The amount of environmental objective function (CO_2 produced)
Optimize the first objective	8270411439.9	26039057845.3
Optimize the second objective	17815094835.4	16637097025.7

As shown in Table 6, when the first objective is optimized, the total cost is about 8 billion Rials. However, if the second constraint is to be optimized, the total costs will increase to about 17 billion Rials. The same procedure exists for the second constraint function. Therefore, it can be concluded that the objective functions conflict with each other and the independent optimization of a constraint cannot provide an appropriate amount of other constraint. Accordingly, due to the high quality of the MOGWO method, this problem is optimized with this algorithm in order to arrive at a set of non-dominated solutions. These non-dominated solutions are originally the set of optimal answers to the problem that the decision maker can choose the most appropriate one and perform it. Fig. 9 shows the set of solutions.

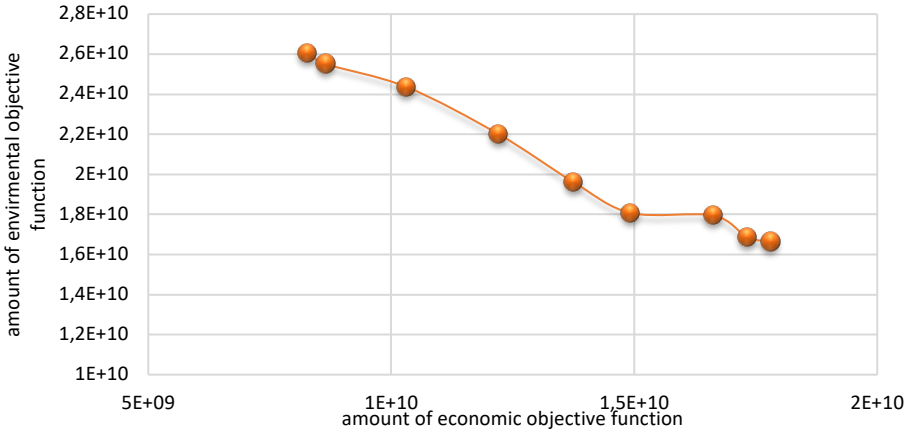

Figure 9. Effective boundary of mathematical model on case study problem

As shown in Fig. 2, if the decision maker wants to reduce the overall costs, the chain will have a weaker performance in terms of the environmental index. On the other hand, if he seeks to reduce the environmental impact, he will have to impose more costs on the

chain. Therefore, in general, the characterization of this optimization framework presented in this study is based on the principle that having only one ideal solution can not cover all real conditions and may not be executable. Therefore, a set of optimal answers can be provided as shown in Fig. 2 for decision makers of the supply chain to select and execute the most appropriate according to different constraints and conditions.

5. Conclusion and future researches

A developed mathematical model for supply chain design was presented in this research concerning environmental considerations. The main innovation of this research is the development of a mathematical model based on the dairy industry in the country and the use of a new multi-functional algorithm called MOGWO. The results of this study indicate that the economic and environmental objectives in the supply chain are conflicting, and their independent optimization does not have the required efficiency for use in the supply chain. On the other hand, the MOGWO algorithm performs better than the Epsilon constraint method. This algorithm is distinct from the Epsilon constraint method in the NPS, SNS, and Max Spread indices and has superiority. Regarding the solving time, the average solving time of this algorithm was about 0.1% of the solving time of the Epsilon constraint method. Therefore, the efficiency of this multi-objective algorithm has been confirmed with multiple indicators, and this algorithm can be considered as an appropriate tool for solving supply chain design issues.

In this study, in particular, supply chain network design is optimized based on the key concepts of the circular economy. One of the most important value-added created in this study is that it is possible to implement the supply chain in the dairy industry. This helps industry executives reduce their environmental pollution and generate more profitable sales and sales. Moreover, using MOGWO is suggested for other researchers to use in supply chain network design.

To develop this research and present future research, it is suggested that uncertainty be taken into account in model parameters such as customer demand, production, and distribution costs in the mathematical model. This uncertainty can be implemented with feasibility planning or robust optimization approaches. Moreover, another novel meta-heuristic algorithm like invasive weed optimization is suggested.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors sincerely appreciate the editor and reviewers for their time and valuable comments.

References

[1] Aghaahmadi, F.Mahouchi, M. (2017). Supply chain design based on multi-stage random planning. Second National Conference on Industrial Engineering and Systems. Najafabad Islamic Azad University, Department of Industrial Engineering.

[2] Ahmadinezhad, S. Karimizarchi, F. (2018).Selection of a business strategy for managing green supply chain management using the method of network analysis process. Man and the environment.

[3] Akbarijoukar, M.R.Mousareza, A. (2016). Design of complete packet ring network chain under uncertainty of demand and product return conditions. Industrial Engineering Journal, 50 (3), 355-369.

[4] Ali, M., Kennedy, C. M., Kiesecker, J., & Geng, Y. (2018). Integrating biodiversity offsets within Circular Economy policy in China. *Journal of Cleaner Production*, 185, 32-43.

[5] Babaee Tirkolaee, E., Goli, A., Pahlevan, M., & Malekalipour Kordestanizadeh, R. (2019). A robust bi-objective multi-trip periodic capacitated arc routing problem for urban waste collection using a multi-objective invasive weed optimization. *Waste Management & Research*, *37*(11), 1089-1101.

[6] Batista, L., Gong, Y., Pereira, S., Jia, F., & Bittar, A. (2018). Circular supply chains in emerging economies–a comparative study of packaging recovery ecosystems in China and Brazil. *International Journal of Production Research*, 1-21.

[7] Beheshtinia, A. (2017). Presenting a Genetic Algorithm for the Problem of Vehicle Routing Integrity and Production Timing in the Supply Chain (Case Study: Medical Supply Chain). Industrial Engineering Journal, 51 (2), 147-160.

[8] Bressanelli, G., Perona, M., & Saccani, N. (2018). Challenges in supply chain redesign for the Circular Economy: a literature review and a multiple case study. *International Journal of Production Research*, 1-21.

[9] Davoodi, S. M. R., & Goli, A. (2019). An integrated disaster relief model based on covering tour using hybrid Benders decomposition and variable neighborhood search: Application in the Iranian context. *Computers & Industrial Engineering*, *130*, 370-380.

[10] del Mar Alonso-Almeida, M., & Rodriguez-Anton, J. M. (2019). Circular Supply Chain and Business Model in Apparel Industry: An Exploratory Approach. In *The Circular Economy and Its Implications on Sustainability and the Green Supply Chain* (pp. 66-83). IGI Global.

[11] Esposito, M., Tse, T., & Soufani, K. (2018). Introducing a Circular Economy: New Thinking with New Managerial and Policy Implications. *California Management Review*, 60(3), 5-19.

[12] Fahimnia, B., Davarzani, H., & Eshragh, A. (2018). Planning of complex supply chains: A performance comparison of three meta-heuristic algorithms. *Computers & Operations Research*, 89, 241-252.

[13] Farooque, M., Zhang, A., Thurer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Journal of Cleaner Production*.

[14] Fazli-Khalaf, M., Mirzazadeh, A., & Pishvaee, M. S. (2017). A robust fuzzy stochastic programming model for the design of a reliable green closed-loop supply chain network. Human and Ecological Risk Assessment: An International Journal, 23(8), 2119-2149

[15] Gandhi, M. A. (2018). Ordering of components of Green Supply Chain Practices jointly impacting the individual components of Green Supply Chain Performance–An Empirical Study of the Indian Automobile Manufacturing Sector. Archives of Business Research, 6(1).

[16] Garza-Reyes, J. A., Salomé Valls, A., Peter Nadeem, S., Anosike, A., & Kumar, V. (2018). A circularity measurement toolkit for manufacturing SMEs. *International Journal of Production Research*, 1-25.

[17] Ghorbanpour, P., & Shamsodin, N.(2016). Designing a Structural Model for Green Supply Chain Management Actions Using Fuzzy Interpretative Structural Modeling Approach. Investigating operations in its applications, 13.

[18] Goli, A., Babaee Tirkolaee, E., & Soltani, M. (2019). A robust just-in-time flow shop scheduling problem with outsourcing option on subcontractors. *Production & Manufacturing Research*, *7*(1), 294-315.

[19] Goli, A., & Davoodi, S. M. R. (2018). Coordination policy for production and delivery scheduling in the closed loop supply chain. *Production Engineering*, *12*(5), 621-631.

[20] Goli, A., & Malmir, B. (2020). A covering tour approach for disaster relief locating and routing with fuzzy demand. *International Journal of Intelligent Transportation Systems Research,* 18(1), 140-152.

[21] Goli, A., Khademi Zareh, H., Tavakkoli-Moghaddam, R., & Sadeghieh, A. (2018). A comprehensive model of demand prediction based on hybrid artificial intelligence and metaheuristic algorithms: A case study in dairy industry. *Journal of Industrial and Systems Engineering*, *11*(4), 190-203.

[22] Goli, A., Zare, H. K., Tavakkoli-Moghaddam, R., & Sadeghieh, A. (2019). Application of robust optimization for a product portfolio problem using an invasive weed optimization algorithm. Numerical Algebra, *Control & Optimization,* 9(2), 187.

[23] Goli, A., Zare, H. K., Tavakkoli-Moghaddam, R., & Sadegheih, A. (2019). Multiobjective fuzzy mathematical model for a financially constrained closed-loop supply chain with labor employment. *Computational Intelligence*.

[24] Goli, A., Zare, H. K., Tavakkoli-Moghaddam, R., & Sadeghieh, A. (2019). Hybrid artificial intelligence and robust optimization for a multi-objective product portfolio problem Case study: The dairy products industry. *Computers & Industrial Engineering*, *137*, 106090.

[25] Golpîra, H., Zandieh, M., Najafi, E., Sadi-Nezhad, S. (2017). A multiobjective, multi-echelon green supply chain network design problem with risk-averse retailers in an uncertain environment. Scientia Iranica.Transaction E: Industrial Engineering, 24(1), 413-423.

[26] Goodarzian, F., Wamba, S. F., Mathiyazhagan, K., & Taghipour, A. (2021). A new bi-objective green medicine supply chain network design under fuzzy environment: Hybrid metaheuristic algorithms. *Computers & Industrial Engineering,* 160, 107535.

[27] Hassani, A. (2010). Design of the supply chain outstanding corrosive goods. Master Thesis for Industrial Engineering, The trend of industries, Tarbiat Modares University.

[28] Howard, M., Hopkinson, P., & Miemczyk, J. (2019). The regenerative supply chain: a framework for developing circular economy indicators. *International Journal of Production Research*, *57*(23), 7300-7318.

[29] Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 127, 221-232.

[30] Kumar, V., Sezersan, I., Garza-Reyes, J. A., & AL-Shboul, M. A. (2018). Circular economy in the manufacturing sector: Benefits, opportunities and barriers. *Management Decision*. (In press)

[31] Liang, L., & Kouesta, H. J. (2018). Green Design of a Cellulosic Butanol Supply Chain Network: A Case Study of Sorghum Stem Bio-butanol in Missouri. BioResources, 13(3), 5617-5642.

[32] Mangla, S. K., Luthra, S., Mishra, N., Singh, A., Rana, N. P., Dora, M., & Dwivedi, Y. (2018). Barriers to effective circular supply chain management in a developing country context. *Production Planning & Control*, 29(6), 551-569.

[33] Miranda-Ackerman, M. A., Azzaro-Pantel, C., & Aguilar-Lasserre, A. A. (2017). A green supply chain network design framework for the processed food industry: Application to the orange juice agrofood cluster. Computers & Industrial Engineering, 109, 369-389.

[34] Mortazavi, S., & Seyfbarghi, M., (2018). Two-objective modeling of allocation problem in a green supply chain considering the transport system and CO2 emissions. Industrial Management Outlook. 29, 163-185.

[35] Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, 140(3), 369-380.

[36] Nouridarian, M. Taleezadeh, A. (2018). Developing a model of economic production in integrated and non-integrated level supply chains, taking into account the optimal inventory control policy. Industrial Engineering Journal, 52 (1), 125-137.

[37] Nurjanni, K. P., Carvalho, M. S., & Costa, L. (2017). Green supply chain design: A mathematical modeling approach based on a multi-objective optimization model. International Journal of Production Economics, 183, 421-432.

[38] Pasuki, T., Çalik, A., Kumpf, A., & Weber, G. W. (2019). A New Model for Lean and Green Closed-Loop Supply Chain Optimization. In Lean and Green Supply Chain Management (pp. 39-73). Springer, Cham.

[39] Rad, R. S., & Nahavandi, N. (2018). A novel multi-objective optimization model for integrated problem of green closed loop supply chain network design and quantity discount. Journal of Cleaner Production.

[40] Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? - Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, 135, 246-264.

[41] Saffar, M.Shakouriganjavi,H. Razmi, GH .(2017). Designing a Supply Chain Network Considering Environmental Factors under Uncertainty and Solving It with Multi-objective Differential Evolutionary Algorithms (MODE). Journal of Environmental Science and Technology, 19, 209-221.

[42] Sangaiah, A. K., Tirkolaee, E. B., Goli, A., & Dehnavi-Arani, S. (2019). Robust optimization and mixed-integer linear programming model for LNG supply chain planning problem. *Soft Computing*, 1-21.

[43] Su, B., Heshmati, A., Geng, Y., & Yu, X. (2013). A review of the circular economy in China: moving from rhetoric to implementation. *Journal of Cleaner Production*, 42, 215-227.

[44] Tarokh, M.& Gouke, M. (2010). An overall model for optimizing reverse logistics network design with uncertainty. Industrial Engineering Journal of Industrial Engineering, 1392-193-159.

[45] Tirkolaee, E. B., Alinaghian, M., Hosseinabadi, A. A. R., Sasi, M. B., & Sangaiah, A. K. (2019a). An improved ant colony optimization for the multi-trip Capacitated Arc Routing Problem. *Computers & Electrical Engineering*, 77, 457-470.

[46] Tirkolaee, E. B., Goli, A., & Weber, G. W. (2019b). Multi-objective Aggregate Production Planning Model Considering Overtime and Outsourcing Options Under Fuzzy Seasonal Demand. In *Advances in Manufacturing II* (pp. 81-96). Springer, Cham.

[47] Tirkolaee, E. B., Hosseinabadi, A. A. R., Soltani, M., Sangaiah, A. K., & Wang, J. (2018). A hybrid genetic algorithm for multi-trip green capacitated arc routing problem in the scope of urban services. *Sustainability*, 10(5), 1366.

[48] Zhang, H., & Yang, K. (2018). Multi-Objective Optimization for Green Dual-Channel Supply Chain Network Design Considering Transportation Mode Selection. International Journal of Information Systems and Supply Chain Management (IJISSCM), 11(3), 1-21.

[49] Zhuo, H., & Wei, S. (2017). Gaming of green supply chain members under government subsidies—based on the perspective of demand uncertainty. In Proceedings of the Tenth International Conference on Management Science and Engineering Management (pp. 1105-1116). Springer, Singapore.

Received 11.07.2021, Accepted 30.03.2022