RAIRO-Oper. Res. 53 (2019) 963–990
https://doi.org/10.1051/ro/2019018

RAIRO Operations Research
www.rairo-ro.org

A FUZZY MULTI-OBJECTIVE PROGRAMMING APPROACH TO DEVELOP A GREEN CLOSED-LOOP SUPPLY CHAIN NETWORK DESIGN PROBLEM UNDER UNCERTAINTY: MODIFICATIONS OF IMPERIALIST COMPETITIVE ALGORITHM

Mohammad Bagher Fakhrzad* and Fariba Goodarzian

Abstract. The last decade has seen a numerous studies focusing on the closed-loop supply chain. Accordingly, the uncertainty conditions as well as the green emissions of facilities are still open issues. In this paper, a new fuzzy multi-objective programming approach is to present for a production-distribution model in order to develop a multi-product, multi-period and multi-level green closed-loop supply chain network problem, which this model is formulated as multi-objective mixed linear integer programming (MOMILP). In regards to offered fuzzy multi-objective model, three conflicting goals are exited, simultaneously. The objective functions are to minimizing the total cost, minimizing the gas emissions costs due to vehicle movements between centers, and maximizing the reliability of delivery demand due to the reliability of the suppliers. To get closer to real-world applications, the parameters of model are considered by fuzzy numbers. Another novelty of proposed model is in the solution methodology. To solve the model, this study not only uses a well-known Imperialist Competitive Algorithm (ICA) but a number of new modifications of ICA (MICA) also have been provided to address the proposed problem, which is to demonstrate the efficiency and performance of the proposed algorithm with other algorithms included: SA, ICA, ACO, GA, and PSO are compare. Finally, different analyses with a variety of problem complexity in different sizes are performed to assess the performance of algorithms as well as some sensitivity analyses on the efficiency of model are studied.

Mathematics Subject Classification. 97M50.

Received October 28, 2018. Accepted January 29, 2019.

1. Introduction

In the past decade, due to the increasing importance of economic competitiveness, the improvement of service levels, legal pressures and environmental concerns in the area of worn-out products, the issue of closed-loop supply chain has attracted many researchers [33]. For this reason, companies need to focus on closed loop supply chain activities such as reuse, recycling, re-production and disposal [17]. Closed-loop supply chain network consists of forward and reverse supply chains. The forward supply chain consists of a set of activities, which the raw materials are converted into final products. Managers are trying to improve the performance of the forward supply chain in areas such as demand management, logistics, and order execution. The concept

Keywords. Closed-loop supply chain, fuzzy logic, multi-objective optimization, imperialist competitive algorithms.

Department of Industrial Engineering, Yazd University, PO Box 8915818411, Yazd, Iran.
*Corresponding author: mfakhrzad@yazd.ac.ir

of reverse supply chain design is provided with concepts such as recycling, re-cycling or reuse of products. In general, reverse supply chain network design involves determining the number, location, and capacity of the collection centers, recovery, and disposal inventory of each site, as well as the amount of flow between each pair of facilities [24].

Regarding to scientific directions of this research scope, a green supply chain is a supply chain in which environmental considerations have been addressed during its design [46]. Green supply chain is a management approach that seeks to minimize the environmental and environmental impacts of products and services and social collections. Also, green Supply Chain Management is an integrated supply chain of green purchases from suppliers to manufacturing, customer delivery and reverse logistics [2–16,18,19,21–23,26–32,34–45]. In addition, the idea of green supply chain management is to eliminate or minimizes waste (energy, greenhouse gas, chemical/hazardous emissions). GSCM is as an important innovation to the organization in developing strategies to achieve shared profit and market goals by reducing environmental risks and increasing its environmental efficiency and performance [16]. In some references and scientific resources, the concept of closed-loop supply chain management and green supply chain management are commonly used in each other, but these two concepts are slightly different from each other; closed-loop supply chain management involves economic and sustainability Social and environmental. Therefore, the concept of closed-loop supply chain management is wider than the green supply chain management, and green supply chain management is part of the closed-loop supply chain management [2–14, 18, 19, 21–23, 25–32, 34–45]. In recent years, supply chain network design attracted many researchers. Supply chain management has changed due to the high speed of globalization and increased technology levels, which the pressures from competition, the organizations have been forced to increase and improve cooperation in the supply chain, which involves the combination of different processes. Therefore, supply chain network design is one of the most important strategic decisions, which is to determine the location and number of facilities in the network, the inventory of each facility, and the quantity of the flow of transmission between them [10]. In this regard, the design and creation of the supply chain as a strategic decision examines how to convert raw materials to the final product. These processes are based on the supply chain, including suppliers, manufacturers, distributors, retailers and customers. Also, a closed-loop supply chain network can include multiple production centers, collection centers, demand and product markets [45]. The goal of supply chain design, in addition to locating facilities, is to minimize costs such as purchasing, manufacturing, transportation, and so on. Nowadays, one of the key issues in the supply chain design is uncertainty, one of the reasons for this problem is the lack of certain and exact information as well as the dynamics and complexity of supply chain components. Method such as fuzzy programming is used to solve this problem, which fuzzy programming is used in obscure environments, including inexact and fuzzy parameters [21].

Dealing with the problem of designing and programming a green closed-loop supply chain as a NP-hard problem requires an efficient approach to provide a reliable and effective solution in a logical time, moreover, in problems with realistic dimensions. Prior articles which have attempted to provide new solutions to the problem confirm this. As a result, using different precise and imprecise approaches have been overviewed. In larger dimensions and in more complex problems, using precise approaches are extremely time-consuming or impossible. In order to provide a solution for these types of problems, meta-heuristic algorithm approaches could be used to reach an acceptable solution in a relatively shorter time. Also, the components of the green closed-loop supply chain considered in this study include customers, suppliers, distribution centers/collection, production/rehabilitation, and destruction. This chain has four forward levels and tow reverse levels, which will be modeled with a multi-objective fuzzy approach. The model reviewed in this article, is a multi-product, multi-level, multi-period model.

The new approach of the developed model of this study considers resuscitation and recycle simultaneously. The products consist of several components which can be disassembled and used as a restored components or be recycled as scrap products. Various similar instances can be mentioned in the automotive industry, electronic, iron and steel, plastics, paper making, digital equipment, and computer equipment. This approach made the proposed multi-product model so complicated, especially in terms of solving large-scale instances with metaheuristic methods. Strictly speaking, a multi-product, multi-level, multi-period model is developed in this study as a more practical model.

In the following, Section 2 presents a review of the relevant literature review. The problem addressed in this study is defined, we propose a multi-objective mixed integer linear programming model, and the proposed fuzzy approach to solve the problem is outlined in Section 3. Section 4 includes the solution and the suggested algorithm. In Section 5, Numerical analysis of the proposed method is presented. Finally, in Section 6, the results of this article are presented and future research areas are suggested.

2. Literature review

The literature reviewed shows that the green closed-loop supply chain under uncertainty problems are typically solved through heuristic and metaheuristic algorithms, or exact methods procedure. Since the problem is uncertainty (NP)-hard, solving and obtaining the optimal solutions for medium and large size problems by utilize of exact methods require long run time; so, seeking optimal solutions is often impractical and it is necessary to use efficient metaheuristic methods. Therefore, metaheuristic methods are often utilized in the recent related studies in order to solve the problem in a shorter run time.

2.1. Closed-loop supply chain

In recent year, several studies have been carried out on the green closed-loop supply chain problem under uncertainty. Pishvaee *et al.* proposed a model for integrated logistics network design to avoid the sub-optimality caused by a separate, sequential design of forward and reverse logistics networks. Also, a bi-objective mixed integer programming formulation is developed to minimize the total costs and maximize the responsiveness of a logistics network [31]. Following the mentioned study, Pishvaee *et al.* developed a robust optimization model for handling the inherent uncertainty of input data in a closed-loop supply chain network design problem. Also, they developed a deterministic mixed-integer linear programming model for designing a closed-loop supply chain network [32].

Ramezani *et al.* presented a stochastic multi-objective model for forward/reverse logistic network design under an uncertain environment including three echelons in forward direction and two echelons in backward direction [34]. Hassanzadeh and Zhang proposed a closed-loop supply chain network with multiple manufactures, warehouses, demand markets and products. They developed linear integer planning to reduce the total cost. In their work, the effect of uncertainty on demand and returns in networks is considered using contingency programming. They developed a mixed-integer linear programming model for closed-loop supply chain, which aim is minimizing the total cost. Also, a CLSC network is investigated which includes multi-plants, collection centers, demand markets, and products [6]. Özkir and Basligil developed fuzzy logic to model the activities in a closed-loop supply chain in a multi objective. They considered the model to investigate the effects of the quality and quantity of returned products on customer satisfaction and supply chain profitability. The objectives of this model include maximizing service levels, maximizing buyer and seller satisfaction in the chain, and decreasing the total cost in the supply chain network [28].

Ramezani *et al.* designed a logistic network is a strategic and critical problem. They addressed the application of fuzzy sets to design a multi-product, multi-period, closed-loop supply chain network. The objectives of this model include maximization of profit, minimization of delivery time, and maximization of quality. They considered a fuzzy optimization approach is adopted to convert the developed fuzzy multi-objective mixed-integer linear program [35]. Alshamsi *et al.* proposed a mixed-integer linear programming (MILP) in reverse logistics using a case study approach [4]. Talaei *et al.* developed a robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem. They effort have been made to investigate a facility location/allocation model for a multi-product closed-loop green supply chain network consisting of manufacturing/remanufacturing and collection/inspection centers as well as disposal center and markets. They proposed a mixed-integer linear programming model capable of reducing the network total costs. Moreover, the model has been developed using a robust fuzzy programming approach to investigate the effects of uncertainties of the variable costs, as well as the demand rate, on the network design [41]. Kaya and Urek developed a mixed integer nonlinear programming facility location-inventory-prices model. Also, they analyzed a network design problem for a closed-loop supply chain [23]. Finally, Hassanzadeh and Baki developed a multi-objective mixed-integer linear programming model for a closed-loop supply chain network using a case study approach in Canada. Also, they considered global factors, including exchange rates and customs duties [5].

2.2. Green supply chain

Attention to the concepts of green supply chains has been on the rise in the recent years in their studies. Abdallah *et al.* developed a mixed integer programming for the carbon-sensitive supply chain network, which minimizes emissions throughout the supply chain by taking into consideration green procurement also known as environmental sourcing [2]. Su studied focuses on the relationship between new materials and recycled materials under varying production cost, machine yield and capacity and energy consumption. They developed Fuzzy multi-objective linear programming models are utilized to analyze factors in the relative cost-effectiveness and CO_2 emissions. In the following, proposed model evaluates cost-effectiveness and CO_2 emissions and integrates multi-component and multi-machine functions for remanufacturing systems [40]. Sari proposed a new hybrid fuzzy MCDM approach to evaluate green supply chain management practices [38]. Nurjanni *et al.* developed a novel green supply chain (GSC) design approach with the trade-offs between environmental and financial issues in order to reduce negative impacts on the environment caused by the increasing levels of industrialization. Also, they proposed a multi-objective optimization mathematical model to minimize overall costs and carbon dioxide emissions when setting the supply chain [27].

2.3. Uncertainty in supply chains

Several ways have been suggested to consider uncertainties, including applying fuzzy logic. In cases when the available information is vague, fuzzy set theory and fuzzy mathematical planning could be used to deal with the actual real world actual uncertainties. Uncertainty in supply chain has been widely studied in the recent decade. Badri *et al.* used a two-stage stochastic programming model to deal with parameter uncertainty in the value-based supply chain network design [9]. Similarly, Jabbarzadeh *et al.* applied a stochastic robust optimization model to explain uncertainty in the design of a closed-loop supply chain network [20].

Tsao *et al.* used fuzzy probabilistic multi-objective programing to model their problem [44]. Tosarkani and Amin applied a fully fuzzy programming method is used to address the uncertainty [43]. Haddadsisakht and Ryan carried out a study with the premise of stochastic demand uncertainty [18]. Babbar and Amin used a fuzzy approach to a multi-objective mathematical model their suggested supply chain design problem [8].

2.4. Necessity of modified metaheuristic in this research scope

In prior research, solving the problems of green closed-loop supply chains has been done in different ways. Most of the suggested solutions are production-distribution solutions using mathematical modeling software packages such as Lingo, GAMS, and Matlab. The problems modeled with these software packages generally have fewer echelons. Diabat and Deskoores used GAMS to solve their model in smaller scales and genetic algorithm for problems in large scales [11]. Hiassat *et al.* used genetic algorithm (GA) to solve location-inventory-routing problem [19]. Al-Salem *et al.* used CPLEX to provide an MIP model [3]. Mogale *et al.* used NSGA-II and NCRO algorithms to propose for a novel integrated multi-objective, multi-modal, and multi-period mathematical model [26]. Sahebjamnia *et al.* used LINGO and MOPSO, MOICA, and NSGA-II algorithms to solve their multi-objective involving a multi-period single-product model. Also, they a reformulated supply chain network which they converted a nonlinear model to a linear one [37]. Piroozfard *et al.* used NSGA-II and SPEA2 algorithms in order to solve a developed bi-objective optimization problem [30]. Shojaie and Raoofpanah implemented two algorithms is called simulated annealing (SA) and non-dominated sorting genetic algorithm (NSGA-II). Also, they developed multi-objective linear integer mathematical programming [39].

A summary of the literature review and the role of the current paper is presented in Table 1.

TABLE 1. Summary of the literature review.

No.	Paper	Multi-objective	Multi-period	Uncertainty approach	Green approach	Closed-loop	Modified meta-heuristic	Large scale instances	Model	Solve method
1	Pishvaee *et al.* (2011)	✓		✓	✓				MIP	
2	Ramezani *et al.* [34]	✓	✓	✓		✓				
3	Talaei *et al.* [41]	✓		✓		✓			MILP	
4	Amin and Zhang [6]	✓		✓		✓			MILP	Weighed sums and ε-constraint
5	Shojaie and Raoof-panah [39]	✓		✓	✓				LIP	SA, NSGA-II
6	Jabbarzadeh *et al.* [36]		✓			✓				Lagrangian relaxation
7	Tsao *et al.* [44]	✓		✓						
8	Tosarkani and Amin [43]	✓	✓	✓		✓				ε-constraint, Fuzzy ANP
9	Babbar and Amin [8]	✓		✓	✓					
10	Sahebjamnia *et al.* [37]	✓	✓					✓	MINLP	MOPSO, MOICA, NSGA-II
12	Mogale *et al.* [26]	✓	✓						MINLP	NSGA-II, NCRO
11	This Research	✓	✓	✓	✓	✓	✓	✓	MILP	SA, ICA, ACO, GA, PSO, MICA

Based on the literature review and the associated summarization in Table 1 (which has been discussed in this section), it is evident that modeling and solving the problem of a multi-period, multi-product, and multi-level green closed loop supply chain in a large scale which considers environmental and social responsibility issues could be an interesting and relevant research topic, especially in case each of the products consists of multiple components and each component consists of various raw materials. This study follows to provide a solution for the proposed model considering the concerns of environmental and social impacts of a green supply chains. The contributions of this paper can be roughly summarized as follows:

– This paper proposes a multi-objective mathematical model that takes into account three indispensable dimensions of a green closed-loop supply chain (reliability, exhaust gases, and supply chain cost). The purpose of this model is to maximize supplier reliability, minimize exhaust gases and minimize the supply chain network design costs including fixed set-up costs for each facility, transportation cost, and operating costs to achieve the best structure for the green closed-loop supply chain network by determining the location and number of facilities in each layer and the amount of flow of products/pieces between the facilities of each layer. The proposed model is expected to help the planners to determine the number and location of facilities (*i.e.*, production and distribution centers) and the product flows in the network.

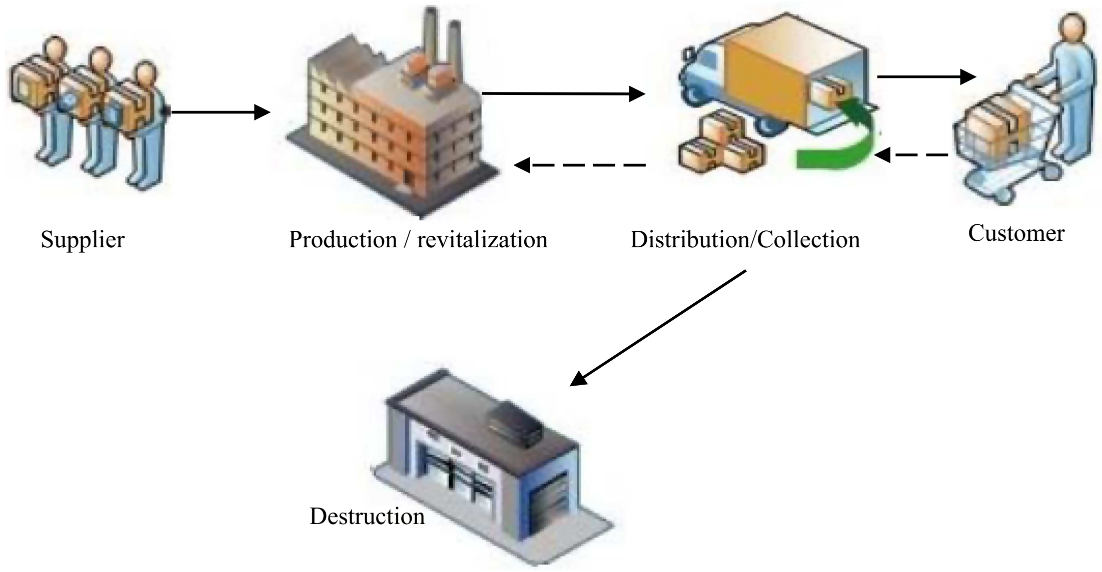

Figure 1. The studied model and flows among the centers.

– The developed model is solved using an Imperialist Competitive Algorithm (ICA) and GAMS software. The ICA algorithm is updated in order to achieve the solutions faster and more reliable. Strictly speaking, a number of new modifications of ICA is developed in the first stage of the original algorithm, which can generate the feasible solution absolutely faster. In fact, the initial step of the presented ICA algorithm starts with a developed meta-heuristic algorithm.
– This study proposes a fuzzy multi-objective programming approach, to formulate a green closed-loop supply chain network design problem under an uncertain environment. Subsequently, fuzzy multi-objective programming is used to solve the proposed model. This approach would dominate other approaches used in previous studies owing to its use of fuzzy numbers for discrete distributions and stochastic variables for continuous distributions to deal with uncertainties. Also, In the model presented, transportation costs, production and reproduction operations, distribution coefficients CO_2, return rates, product destruction and recovery, facility capacity, processing time and set up, and supplier reliability index are considered as fuzzy due to the nature of the uncertainty in the real world.

Consequently, this paper tries to elevate the closed-loop supply chain problem in both modeling and solution algorithm regarding green factors.

3. Problem description

The problem addressed in this section is extensively described. First, some general issues in the model are presented, then uncertainties in the system are discussed. Later, the premises of the problem are presented, and finally, following a presentation of some of the parameters and variables of the problem, the solution is discussed. The model consists of four levels in a forward chain and includes suppliers, raw material, distribution centers, and customer centers. It also comprises two levels in the returns chain involving used collection centers and reproduction. These levels are illustrated in Figure 1.

The supply chain network discussed in this paper is a multi-product, multi-level, and multi-period a logistics network under uncertainty conditions that includes several suppliers, production/reproduction factories, distribution/collecting centers, customer centers, and destruction. Therefore, it is capable of supporting a variety of industries in reverse logistics networks, in which they rehabilitate and recycling of end-of-life products. As shown in Figure 1, in forward flow, the factories produce the parts or raw materials provided through the suppliers. Then, produce their products and send them through the distribution centers to the customer centers. On the way backward to the products used, which returned for any reason to the collection centers. Also, after separation and recovery, they are divided into two groups of recoverable pieces and scrap products. The intact pieces, usable and repairable to be sent to production centers for re-production, and unused pieces are sent to disposal centers.

In this paper, the proposed green closed-loop supply chain in meant for supplying, collecting, producing, and destructing products that have multiple major components, and each of these components are composed of several raw materials in different quantities. The first objective of this model is to increase the supplier reliability. Minimization of exhaust gases is considered as the second objective. The third objective of the model is to minimize supply chain network design costs including fixed set-up costs for each facility, transportation cost, and operating costs to achieve the best structure for the green closed-loop supply chain network by determining the location and number of facilities in each layer and the amount of flow of products/pieces between the facilities of each layer.

3.1. Uncertainties in the model

In real world and during a supply chain design, various parameters are faced which cannot be considered certain. To reach more realistic results, it is reasonable to incorporate these uncertainties to the possible extent. In this model, uncertainty is considered for all model parameters.

3.2. Three objective green closed-loop supply chain

Designing a green closed-loop supply chain could be done with several objectives. The proposed model in this article has three objectives, namely, increasing the supplier reliability, reducing the exhaust gases, and minimizing supply chain network design costs. This model is a multi-product, multi-level, and multi-period model for deciding on the required number of centers, their locations, and the flow of products between them, while reaching the stated objectives. The defined sets for modelling this problem and the symbols used in modelling this closed-loop supply chain are described.

Set	Definition
I	Index of fixed supplier locations ($i = 1, 2, \ldots, I$)
J	Index of potential locations for production/rehabilitation centers ($j = 1, 2, \ldots, J$)
K	Index of potential locations for distribution/collection centers ($k = 1, 2, \ldots, K$)
C	Index of fixed customers locations ($c = 1, 2, \ldots, C$)
F	Index of potential locations for discharge centers ($f = 1, 2, \ldots, F$)
R	Index of manufactured products ($r = 1, 2, \ldots, R$)
T	Index of period time ($t = 1, 2, \ldots, T$)
L	Index of fixed supplier locations ($i = 1, 2, \ldots, I$)

Variable	Description
SP_{rjt}	Amount of product r produced at the production center j in period t
SR_{rjt}	Amount of product r produced at the rehabilitation center j in period t
TRS^{l}_{ijt}	Amount of raw material shipped with transportation l from supplier i to production center j in period t
TPP^{l}_{rjkt}	Amount of product r shipped with transportation l from production center j to distribution center k in period t
TPD^{l}_{rkct}	Amount of product r shipped with transportation l from distribution center k to customer center c in period t
TPC^{l}_{rckt}	Amount of product r shipped with transportation l from customer center c to collection center k in period t
TPr^{l}_{rkjt}	Amount of product r shipped with transportation l from collection center k to rehabilitation center j in period t
$\mathrm{TP}f^{l}_{rkft}$	Amount of product r shipped with transportation l from collection center k to destruction center f in period t
ID_{rkt}	Inventory of product r at the distribution center k in period t
ID_{rkt}	Inventory of product r at the distribution center k in period t
SH_{rct}	Amount of product r unsatisfied demand for customer c in end of period t
NS^{l}_{ijt}	Number of transportation system trips l from supplier i to production center j in period t
NP^{l}_{jkt}	Number of transportation system trips l from production center j to distribution center k in period t
ND^{l}_{kct}	Number of transportation system trips l from distribution center k to customer center c in period t
NC^{l}_{ckt}	Number of transportation system trips l from customer center c to collection center k in period t
NN^{l}_{kjt}	Number of transportation system trips l from collection center k to rehabilitation center j in period t
NRK^{l}_{kft}	Number of transportation system trips l from collection center k to destruction center f in period t
X_{jt}	If the production/rehabilitation center k is to be constructed during the period 1 otherwise 0
U_{kt}	If the distribution/collection center is to be constructed during the period 1 otherwise 0
Z_{ft}	If the destruction center is to be constructed during the period 1 otherwise 0
$r\tilde{p}_{it}$	Price of raw material by supplier i in period t
$de\tilde{m}_{rct}$	Customer demand c for produce r in period t
$\tilde{f}_{jt}$	Fixed cost of construction production center j in period t
$\tilde{f}k_{kt}$	Fixed cost of construction distribution/collection center k in period t
$\tilde{f}f_{ft}$	Fixed cost of construction destruction center f in period t
$p\tilde{c}_{rjt}$	Cost of producing product r in production center j in period t
$p\tilde{c}r_{it}$	Cost of raw material by supplier i in period t
$d\tilde{c}_{rft}$	Cost of destruction product r in destruction center f in period t
$h\tilde{c}_{rkt}$	Cost of holding product r in distribution center k in period t
$sh\tilde{c}_{rct}$	Cost of shortage the unit of product r for customer c in period t
$ft\tilde{s}^{l}_{ijt}$	Fixed cost of sending transportation system l from supplier I to production center j in period t
$ft\tilde{p}^{l}_{jkt}$	Fixed cost of sending transportation system l from production center j to distribution center k in period t
$ft\tilde{d}^{l}_{kct}$	Fixed cost of sending transportation system l from distribution center k to customer c in period t
$ft\tilde{r}^{l}_{kjt}$	Fixed cost of sending transportation system l from collection center k to production center j in period t
$f\tilde{t}f^{l}_{kft}$	Fixed cost of sending transportation system l from collection center k to destruction center f in period t
$f\tilde{t}c^{l}_{ckt}$	Fixed cost of sending transportation system l from customer c to collection center k in period t

Parameter	Description
$vt\tilde{s}^l_{ijt}$	Cost of transportation raw material l from supplier i to production center j with transportation system l in period t
$vt\tilde{p}^l_{rjkt}$	Cost of transportation product r from production center j to distribution center k with transportation system l in period t
$vt\tilde{c}^l_{rckt}$	Cost of transportation returning product r from customer c to collection center k with transportation system l in period t
$vt\tilde{r}^l_{rkjt}$	Cost of transportation reproduce product r from collection center k to production center j with transportation system l in period t
$vt\tilde{f}^l_{rkft}$	Cost of scrap product r from collection center k to destruction f with transportation system l in period t
vtd^l_{rkct}	Cost of transportation product r from collection center k to customer c with transportation system l in period t
$\tilde{v}_r$	Volume of each unit product r
$v\tilde{r}$	Volume of raw material
$cap\tilde{p}_{jt}$	Storage capacity of production center j in period t
$cap\tilde{r}_{jt}$	Storage capacity of rehabilitation center j in period t
$cap\tilde{I}_{it}$	Storage capacity of supplier i in period t
$cap\tilde{d}_{kt}$	Storage capacity of distribution center k in period t
$cap\tilde{d}r_{kt}$	Storage capacity of collection center k in period t
$cap\tilde{f}_{ft}$	Storage capacity of destruction center f in period t
$c\tilde{a}pl_{lt}$	Potential capacity each of transportation tools l in period t
ur_{rt}	The rate of use of the raw material for product production r in period t
$R\tilde{T}_r$	Rate of return product r
$R\tilde{R}_r$	Rate of rehabilitation product r
$R\tilde{F}_r$	Rate of destruction product r
$\tilde{\theta}_1$	Amount of released CO_2 for transportation of each unit raw material from supplier center i to production center j in period t
$\tilde{\theta}_2$	Amount of released CO_2 for transportation of each unit product r from production center j to distribution center k in period t
$\tilde{\theta}_3$	Amount of released CO_2 for transportation of each unit product r from distribution center k to customer center c in period t
$\tilde{\theta}_4$	Amount of released CO_2 for transportation of each unit return product r from customer center c to collection center k in period t
$\tilde{\theta}_5$	Amount of released CO_2 for transportation of each unit return product r from collection center k to destruction center f in period t
$\tilde{\theta}_6$	Amount of released CO_2 for transportation of each unit product r from collection center k to rehabilitation center j in period t
$s\tilde{t}_{rjt}$	Set-up time for production product r in production center j in period t
$p\tilde{t}_{rjt}$	Processing time of product r in rehabilitation center j in period t
$\max\tilde{f}_{jt}$	Maximum available time in production/rehabilitation center j in period t
$R\tilde{I}_{it}$	Index of supplier reliability i for delivery of product in period t
$bigm$	Positive and big number

Here are some assumptions of the problem:

- A multi-level, multi-product and multi-period model has been developed.
- The location of the suppliers and customers is known and fixed.
- The number of facilities that can be opened and their capacity is limited.
- Uncertainty for all parameters of the model is considered.
- The amount of released gas CO_2 due to the transportation system is considered uncertainty.

– All returned products from customers must be collected.
– In order to ensure the supply of materials in the chain, the Reliability Index is defined for each suppliers.

In terms of the above notation, the GCLSC problem can be formulated as (3.1):

$$\begin{aligned}
\operatorname{Min} z_1 = {} & \sum_{\forall i}\sum_{\forall i}(p\tilde{c}r_{it}.\mathrm{SR}_{it}) + \sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(r\tilde{p}_{it}.\mathrm{TRS}^{l}_{ijt}\right)\\
& + \sum_{\forall r}\sum_{\forall j}\sum_{\forall t}(p\tilde{c}_{rjt}.\mathrm{SP}_{rjt}) + \sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(ft\tilde{s}^{l}_{ijt}.\mathrm{NS}^{l}_{ijt}\right)\\
& + \sum_{\forall l}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(ft\tilde{p}^{l}_{jkt}.\mathrm{NP}^{l}_{jkt}\right) + \sum_{\forall l}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(ft\tilde{d}^{l}_{kct}.\mathrm{ND}^{l}_{kct}\right)\\
& + \sum_{\forall l}\sum_{\forall c}\sum_{\forall k}\sum_{\forall t}\left(ft\tilde{c}^{l}_{ckt}.\mathrm{NC}^{l}_{ckt}\right) + \sum_{\forall l}\sum_{\forall i}\sum_{\forall k}\sum_{\forall t}\left(ft\tilde{r}^{l}_{kjt}.\mathrm{NN}^{l}_{kjt}\right)\\
& + \sum_{\forall l}\sum_{\forall f}\sum_{\forall k}\sum_{\forall t}\left(ft\tilde{f}^{l}_{kft}.\mathrm{NRK}^{l}_{kft}\right) + \sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(vt\tilde{s}^{l}_{ijt}.\mathrm{TRS}^{l}_{ijt}\right)\\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(vt\tilde{p}^{l}_{rjkt}.\mathrm{TPP}^{l}_{rjkt}\right) + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(vt\tilde{d}^{l}_{rkct}.\mathrm{TPD}^{l}_{rkct}\right)\\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(vt\tilde{c}^{l}_{rkct}.\mathrm{TPC}^{l}_{rkct}\right) + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall j}\sum_{\forall t}\left(vt\tilde{r}^{l}_{rkjt}.\mathrm{TPr}^{l}_{rkjt}\right)\\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}\left(vt\tilde{f}^{l}_{rkft}.\mathrm{TP}f^{l}_{rkft}\right) + \sum_{\forall r}\sum_{\forall k}\sum_{\forall t}(h\tilde{c}_{rk}.\mathrm{ID}_{rkt})\\
& + \sum_{\forall r}\sum_{\forall c}\sum_{\forall t}(sh\tilde{c}_{rct}.\mathrm{SH}_{rct}) + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}(d\tilde{c}_{rft}.\mathrm{TP}f^{l}_{rkft}) + \sum_{\forall j}\sum_{\forall t}\left(X_{jt}.\tilde{f}_{jt}\right)\\
& + \sum_{\forall k}\sum_{\forall t}(U_{kt}.fk_{kt}) + \sum_{\forall k}\sum_{\forall t}\left(Z_{ft}.\tilde{f}f_{ft}\right).
\end{aligned} \tag{3.1}$$

The first objective function (3.1) is to minimize the supplier reliability of the GCLSC. In this objective, operational and production costs including produce cost each product, distribution cost each product, collection cost each product, reproduction cost, destruction of any product, holding costs, lack of inventory at customer centers, and product transportation costs. the first, second, and third terms are cost and price of raw material by supplier and cost of production product in the network. The fourth to ninth terms are Fixed costs of transportation system incurred during the transmission of supplier, production center, distribution center, customer, collection center, rehabilitation center, and destruction center. The Fixed cost of transportation system depends on the number of transportation system trips in the network. The tenth to fiftieth term deals with costs incurred by a supplier, production center, distribution center, customer, collection center, rehabilitation center, and destruction center. The transportation cost depends on the transportation system provided by the supplier. The last term calculates the shipping cost of the raw material from supplier to production center, the shipping cost of the produce from production center to distribution center, the shipping cost of the returning produce from customer to collection center, the shipping cost of the reproduction produce from collection center to rehabilitation center, the shipping fixed cost from collection center to destruction center, and the shipping cost of the scrap product from collection center to destruction center. It is assumed that the shipping cost depends on the transportation system used in the network. The sixtieth to eightieth terms deals with destruction cost of the produce at the destruction center, holding cost of produce at the distribution center, and shortage cost of the unit produce for customer in the network. At the end, the fixed cost depends on the construction of production, distribution, and destruction centers.

The second objective function is presented in (3.2).

$$\begin{aligned}\text{Min } z_2 = &\sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(\tilde{\theta}_1\cdot \text{TRS}^l_{ijt}\right)+\sum_{\forall l}\sum_{\forall r}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(\tilde{\theta}_2\cdot \text{TPP}^l_{rjkt}\right)\\ &+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(\tilde{\theta}_3\cdot \text{TPD}^l_{rkct}\right)+\sum_{\forall l}\sum_{\forall r}\sum_{\forall c}\sum_{\forall k}\sum_{\forall t}\left(\tilde{\theta}_4\cdot \text{TPC}^l_{rckt}\right)\\ &+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall j}\sum_{\forall t}\left(\tilde{\theta}_5\cdot \text{TPr}^l_{rkjt}\right)+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}\left(\tilde{\theta}_6\cdot \text{TP}f^l_{rkft}\right).\end{aligned} \tag{3.2}$$

The second objective function (3.2) minimizes the environmental impacts of the network. The CO_2 equivalent emissions caused by transportation are presented in the objective function. In this objective function, we assumed that the CO_2 emissions depend on the transportation model, fuel usage, and geographical distances; additionally, it is assumed that the production, supplier, distribution, customer, collection, destruction centers are committed to green development goals.

The second objective function is presented in (3.3).

$$\text{Max } z_3 = \sum_{\forall l}\sum_{\forall r}\sum_{\forall t}\frac{\sum\limits_{\forall j}\dfrac{\sum\limits_{\forall i}\left(R\tilde{I}_i\cdot \text{TRS}^l_{ijt}\right)}{ur_r}}{\sum\limits_{\forall c} de\tilde{m}_{rct}}. \tag{3.3}$$

The third objective function (3.3) maximizes the reliability of demand delivery is based on reliability defined for supplier.

Then, the constraints of the model are presented in equations (3.4)–(3.27), as follows:

$$\sum_{\forall l}\sum_{\forall j}\text{TRS}^l_{ijt} = \text{SR}_{it} \quad \forall i,t \tag{3.4}$$

$$\sum_{\forall l}\sum_{\forall k}\text{TPP}^l_{rjkt} = \text{SP}_{rjt} \quad \forall r,j,t \tag{3.5}$$

$$\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\left(\text{TPP}^l_{rjkt}\cdot ur_r\right) = \sum_{\forall l}\sum_{\forall i}\text{TRS}^l_{ijt}+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\left(\text{TPr}^l_{rjkt}\cdot ur_r\right) \quad \forall j,t \tag{3.6}$$

$$\text{SH}_{rct}-\text{SH}_{rc(t-1)}+\sum_{\forall l}\sum_{\forall k}\left(\text{TPD}^l_{rkct}\right) = de\tilde{m}_{rct} \quad \forall r,c,t \tag{3.7}$$

$$\sum_{\forall l}\sum_{\forall k}\text{TPC}^l_{rckt} = \left(de\tilde{m}_{rc(t-1)}-\text{SH}_{rc(t-1)}\right)\times R\tilde{T} \quad \forall r,c,t \tag{3.8}$$

$$\sum_{\forall l}\sum_{\forall j}\text{TPr}^l_{rkjt} = \left(R\tilde{R}\cdot\sum_{\forall l}\sum_{\forall c}\text{TPC}^l_{rkct}\right) \quad \forall r,k,t \tag{3.9}$$

$$\sum_{\forall l}\sum_{\forall f}\text{TP}f^l_{rkft} = \left(\left(1-R\tilde{R}\right)\cdot\sum_{\forall l}\sum_{\forall c}\text{TPC}^l_{rckt}\right) \quad \forall r,k,t \tag{3.10}$$

$$\sum_{\forall l}\sum_{\forall j}\text{TPP}^l_{rjkt}-\text{ID}_{rkt}+\text{ID}_{rk(t-1)} = \sum_{\forall l}\sum_{\forall j}\text{TPD}^l_{rkct} \quad \forall r,k,t \tag{3.11}$$

$$\sum_{\forall r}\left(\text{ID}_{rkt}\cdot\tilde{v}_r\right)\le ca\tilde{p}d_k \quad \forall k,t \tag{3.12}$$

$$\left(v\tilde{r}\cdot \text{TRS}^l_{ijt}\right)\le\left(cap\tilde{l}\cdot \text{NS}^l_{ijt}\right) \quad \forall l,j,i,t \tag{3.13}$$

$$\sum_{\forall r}\left(\tilde{v}_r \cdot \mathrm{TPP}^l_{rjkt}\right) \leq \left(c\tilde{a}pl_l \cdot \mathrm{NP}^l_{jkt}\right) \quad \forall l, j, k, t \tag{3.14}$$

$$\sum_{\forall r}\left(\tilde{v}_r \cdot \mathrm{TPD}^l_{rkct}\right) \leq \left(c\tilde{a}pl_l \cdot \mathrm{ND}^l_{kct}\right) \quad \forall l, k, c, t \tag{3.15}$$

$$\sum_{\forall r}\left(\tilde{v}_r \cdot \mathrm{TPC}^l_{cjkt}\right) \leq \left(c\tilde{a}pl_l \cdot \mathrm{NC}^l_{ckt}\right) \quad \forall l, c, k, t \tag{3.16}$$

$$\sum_{\forall r}\left(\tilde{v}_r \cdot \mathrm{TPr}^l_{rkjt}\right) \leq \left(c\tilde{a}pl_l \cdot \mathrm{NN}^l_{kjt}\right) \quad \forall l, k, j, t \tag{3.17}$$

$$\sum_{\forall r}\left(\tilde{v}_r \cdot \mathrm{TP}f^l_{rkft}\right) \leq \left(c\tilde{a}pl_l \cdot \mathrm{NRK}^l_{kft}\right) \quad \forall l, k, f, t \tag{3.18}$$

$$\sum_{\forall l}\sum_{\forall j}\mathrm{TRS}^l_{ijt} \leq ca\tilde{p}I_i \quad \forall i, t \tag{3.19}$$

$$\sum_{\forall l}\sum_{\forall f}\mathrm{TR}f^l_{rkft} \leq \left(ca\tilde{p}f_f \cdot Z_{ft}\right) \quad \forall r, f, t \tag{3.20}$$

$$\sum_{\forall l}\sum_{\forall k}\mathrm{TPP}^l_{rjkt} \leq \left(ca\tilde{p}p_j \cdot X_{rjt}\right) \quad \forall r, j, t \tag{3.21}$$

$$\sum_{\forall l}\sum_{\forall j}\mathrm{TPP}^l_{rjkt} \leq \left(ca\tilde{p}d_k \cdot U_{ft}\right) \quad \forall r, k, t \tag{3.22}$$

$$\sum_{\forall l}\sum_{\forall c}\mathrm{TPD}^l_{rkct} \leq \left(ca\tilde{p}d_k \cdot U_{ft}\right) \quad \forall r, k, t \tag{3.23}$$

$$\sum_{\forall l}\sum_{\forall i}\mathrm{TPr}^l_{rkjt} + \sum_{\forall l}\sum_{\forall f}\mathrm{TP}f^l_{rkft} \leq \left(ca\tilde{p}d_k \cdot U_{ft}\right) \quad \forall r, k, t \tag{3.24}$$

$$\sum_{\forall l}\sum_{\forall c}\mathrm{TPC}^l_{rckt} \leq \left(ca\tilde{p}dr_k \cdot U_{ft}\right) \quad \forall r, k, t \tag{3.25}$$

$$\sum_{\forall l}\sum_{\forall k}\mathrm{TPr}^l_{rkjt} \leq \left(ca\tilde{p}r_j \cdot X_{rjt}\right) \quad \forall r, j, t \tag{3.26}$$

$$\begin{aligned}&\mathrm{SR}_{it}, \mathrm{SP}_{rjt}, \mathrm{ID}_{rkt}, \mathrm{TP}f^l_{rkft}, \mathrm{TRS}^l_{ijt}, \mathrm{TPK}^l_{rkj}, \mathrm{TPC}^l_{rckt}, \mathrm{TPD}^l_{rkct}, \mathrm{SH}_{rct}, \mathrm{TPP}^l_{rjkt} \geq 0\\&\mathrm{NS}^l_{ijt}, \mathrm{NP}^l_{jkt}, \mathrm{ND}^l_{kct}, \mathrm{NC}^l_{ckt}, \mathrm{NN}^l_{ckt}, \mathrm{NRK}^l_{ck}, X_{rjt}, U_{ft}, Z_{ft} \in \{0,1\}\cdot\end{aligned} \tag{3.27}$$

Constraint (3.4) ensures that all raw materials produced by each supplier must be shipped to factories within the same time period. Constraint (3.5) ensures that all products produced in each supplier must be shipped to distribution centers within the same time period. Constraint (3.6) ensures that, for each raw material in each period, the flow of output from each plant supplier is equal to the total flow of input to this center from all suppliers and collection centers. Constraint (3.7) ensures the shortage balance equation in the past period. Constraints (3.8)–(3.10) ensures the flow of returned products, reproduction and destruction. Constraint (3.11) ensures the balance of inventory in distribution centers. Constraint (3.12) controls the remaining inventory at the distribution center at the end of each period. Constraints (3.13)–(3.18) ensures the transportation system capacity. Constraint (3.19) ensures that, for each raw material, the total flow of output from each supplier to all production centers does not exceed the supplier's capacity. Constraints (3.20)–(3.26) ensures that flow is between points in this flow, which the facility is constructed or selected and also the total flow in any facility does not exceed its capacity. Finally, constraint (3.27) guarantee the binary and positive of decision variables.

3.3. Fuzzy model

In this section, the mathematical model presented in this paper is a mixed integer programming model. Since, in the real world of uncertainty an inevitable factor is inevitable, most of the parameters used are considered triangular fuzzy numbers because of their uncertain nature. In general, the fuzzy programming problem must first be transformed into a definite equivalent problem and then solved with standard methods and the optimal answer is obtained. As a result, the final solution of the problem is obtained with respect to the fuzzy structure of the problem.

In the following, to solve the model, a two-step approach has been used: In the first step, the proposed model with fuzzy parameters is transformed into a certain auxiliary model by Khimens *et al.* [22] method. In the second stage, using the Torabi-Hosseini method [42], we solve the multi-objective certain model, which was obtained in the first stage.

3.3.1. Khimens method

The khimens presented a method for ranking fuzzy numbers. In this method, defining the fuzzy parameters of the objective functions is calculated based on the concepts of expected distance and expected value for triangular fuzzy numbers $\tilde{c} = (c^p, c^m, c^o)$ according to relations (3.28) and (3.29).

$$\begin{aligned}\mathrm{EI}\left(\tilde{c}\right) &= [E_1^c, E_1^c] = \left[\int_0^1 f_c^{-1}\left(x\right)\mathrm{d}x, \int_0^1 g_c^{-1}\left(x\right)\mathrm{d}x,\right] \\ &= \left[\int_0^1 \left(x\left(c^m - c^p\right) + c^p\right)\mathrm{d}x\right] = \left[\int_0^1 \left(x\left(c^o - c^m\right) + c^o\right)\mathrm{d}x\right] = \left[\frac{1}{2}\left(c^p + c^m\right), \frac{1}{2}\left(c^m + c^o\right)\right] \qquad (3.28)\end{aligned}$$

$$\mathrm{EV}\left(\tilde{c}\right) = \frac{E_1^c + E_1^c}{2} = \frac{c^p + 2c^m + c^o}{4}\cdot \qquad (3.29)$$

Based on Khaminz's method, are considered equation (3.30) for constraint $\left(\tilde{a}_i X \geq \tilde{b}_i, i = 1, 2, \ldots, I\right)$.

$$\left(\alpha\frac{a_i^o + a_i^m}{2} + (1-\alpha)\cdot\frac{a_i^p + a_i^m}{2}\right)X \geq \left(\alpha\frac{b_i^o + b_i^m}{2} + (1-\alpha)\cdot\frac{b_i^p + b_i^m}{2}\right)\cdot \qquad (3.30)$$

For equal constraints $\tilde{a}_i X = \tilde{b}_i, i = 1, 2, \ldots, I$ converted into the certain equivalent constraints, are represented as equations (3.31) and (3.32):

$$\left(\frac{\alpha}{2}\frac{a_i^o + a_i^m}{2} + \left(1 - \frac{\alpha}{2}\right)\cdot\frac{a_i^p + a_i^m}{2}\right)X \geq \left(\frac{\alpha}{2}\frac{b_i^o + b_i^m}{2} + \left(1 - \frac{\alpha}{2}\right)\cdot\frac{b_i^p + b_i^m}{2}\right) \qquad (3.31)$$

$$\left(\left(1 - \frac{\alpha}{2}\right)\cdot\frac{a_i^o + a_i^m}{2} + \frac{\alpha}{2}\cdot\frac{a_i^p + a_i^m}{2}\right)X \geq \left(\left(1 - \frac{\alpha}{2}\right)\cdot\frac{b_i^o + b_i^m}{2} + \frac{\alpha}{2}\cdot\frac{b_i^p + b_i^m}{2}\right)\cdot \qquad (3.32)$$

After Dfuzzy by the help of equation (3.29), the membership function for the minimization objective function is obtained using the Torabi-Hessian method of equation (3.33).

$$\mu_F = \begin{cases} 1 & \text{if } \; Z < Z^{\alpha-\mathrm{PIS}} \\ \dfrac{Z^{\alpha-\mathrm{NIS}} - Z}{Z^{\alpha-\mathrm{NIS}} - Z^{\alpha-\mathrm{PIS}}} & \text{if } \; Z^{\alpha-\mathrm{PIS}} < Z < Z^{\alpha-\mathrm{NIS}}\,. \\ 0 & \text{if } \; Z > Z^{\alpha-\mathrm{NIS}} \end{cases} \qquad (3.33)$$

And the membership function for the maximization objective function is obtained using the equation (3.34).

$$\mu_F = \begin{cases} 1 & \text{if } \; Z > Z^{\alpha-\mathrm{PIS}} \\ \dfrac{Z^{\alpha-\mathrm{NIS}} - Z}{Z^{\alpha-\mathrm{PIS}} - Z^{\alpha-\mathrm{NIS}}} & \text{if } \; Z^{\alpha-\mathrm{NIS}} \leq Z \leq Z^{\alpha-\mathrm{PIS}}\,. \\ 0 & \text{if } \; Z > Z^{\alpha-\mathrm{NIS}} \end{cases} \qquad (3.34)$$

In which the positive ideal solution ($\alpha-\text{PIS}$) and the negative ideal solution ($\alpha-\text{NIS}$) for each objective function and at the level of feasibility (α). According to the above equations, the formulation of a certain auxiliary model is equivalent to the main problem model in equations (3.35)–(3.64).

$$
\begin{aligned}
\text{Min}\, z_1 = & \sum_{\forall i}\sum_{\forall i}\left(\left(\left(p\tilde{c}r_{it}^{p}+2p\tilde{c}r_{it}^{m}+p\tilde{c}r_{it}^{o}\right)/4\right)\text{SR}_{it}\right)\\
&+\sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(\left(\left(r\tilde{p}_{it}^{p}+2r\tilde{p}_{it}^{m}+r\tilde{p}_{it}^{o}\right)/4\right)\text{TRS}_{ijt}^{l}\right)\\
&+\sum_{\forall r}\sum_{\forall j}\sum_{\forall t}\left(\left(\left(p\tilde{c}_{rjt}^{p}+2p\tilde{c}_{rjt}^{m}+p\tilde{c}_{rjt}^{o}\right)/4\right)\text{SP}_{rjt}\right)\\
&+\sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(\left(\left(ft\tilde{s}_{ijt}^{l^p}+2ft\tilde{s}_{ijt}^{l^m}+ft\tilde{s}_{ijt}^{l^o}\right)/4\right)\text{NS}_{ijt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(\left(\left(vt\tilde{s}_{ijt}^{l^p}+2vt\tilde{s}_{ijt}^{l^m}+vt\tilde{s}_{ijt}^{l^o}\right)/4\right)\text{TRS}_{ijt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(ft\tilde{p}_{jkt}^{l^p}+2ft\tilde{p}_{jkt}^{l^m}+ft\tilde{p}_{jkt}^{l^o}\right)/4\right)\text{NP}_{jkt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(vt\tilde{p}_{rjkt}^{l^p}+2vt\tilde{p}_{rjkt}^{l^m}+vt\tilde{p}_{rjkt}^{l^o}\right)/4\right)\text{TPP}_{rjkt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(\left(\left(ft\tilde{d}_{kct}^{l^p}+2ft\tilde{d}_{kct}^{l^m}+ft\tilde{d}_{kct}^{l^o}\right)/4\right)\text{ND}_{kct}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(\left(\left(vt\tilde{d}_{rkct}^{l^p}+2vt\tilde{d}_{rkct}^{l^m}+vt\tilde{d}_{rkct}^{l^o}\right)/4\right)\text{TPD}_{rkct}^{l}\right)\\
&+\sum_{\forall r}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(h\tilde{c}_{rk}^{p}+2h\tilde{c}_{rk}^{m}+h\tilde{c}_{rk}^{o}\right)/4\right)\text{ID}_{rkt}\right)+\sum_{\forall r}\sum_{\forall c}\sum_{\forall t}\left(\left(\left(sh\tilde{c}_{rc}^{p}+2sh\tilde{c}_{rc}^{m}+sh\tilde{c}_{rc}^{o}\right)/4\right)\text{SH}_{rct}\right)\\
&+\sum_{\forall l}\sum_{\forall c}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(ft\tilde{c}_{ckt}^{l^p}+2ft\tilde{c}_{ckt}^{l^m}+ft\tilde{c}_{ckt}^{l^o}\right)/4\right)\text{NC}_{ckt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(\left(\left(vt\tilde{c}_{rkct}^{l^p}+2vt\tilde{c}_{rkct}^{l^m}+vt\tilde{c}_{rkct}^{l^o}\right)/4\right)\text{TPC}_{rkct}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall i}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(ft\tilde{r}_{kjt}^{l^p}+2ft\tilde{r}_{kjt}^{l^m}+ft\tilde{r}_{kjt}^{l^o}\right)/4\right)\text{NN}_{kjt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall j}\sum_{\forall t}\left(\left(\left(vt\tilde{r}_{rkjt}^{l^p}+2vt\tilde{r}_{rkjt}^{l^m}+vt\tilde{r}_{rkjt}^{l^o}\right)/4\right)\text{TPr}_{rkjt}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall f}\sum_{\forall k}\sum_{\forall t}\left(\left(\left(ft\tilde{f}_{kft}^{l^p}+2ft\tilde{f}_{kft}^{l^m}+ft\tilde{f}_{kft}^{l^o}\right)/4\right)\text{NRK}_{kft}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}\left(\left(\left(vt\tilde{f}_{rkft}^{l^p}+2vt\tilde{f}_{rkft}^{l^m}+vt\tilde{f}_{rkft}^{l^o}\right)/4\right)\text{TP}f_{rkft}^{l}\right)\\
&+\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}\left(\left(\left(d\tilde{c}_{rft}^{p}+2d\tilde{c}_{rft}^{m}+d\tilde{c}_{rft}^{o}\right)/4\right)\text{TP}f_{rkft}^{l}\right)\\
&+\sum_{\forall j}\sum_{\forall t}\left(X_{jt}\left(\left(\tilde{f}_{j}^{p}+2\tilde{f}_{j}^{m}+\tilde{f}_{j}^{o}\right)/4\right)\right)+\sum_{\forall k}\sum_{\forall t}\left(U_{kt}\cdot\left(\left(f\tilde{k}_{k}^{p}+2f\tilde{k}_{k}^{m}+f\tilde{k}_{k}^{o}\right)/4\right)\right)\\
&+\sum_{\forall k}\sum_{\forall t}\left(Z_{ft}\cdot\left(\left(\tilde{f}f_{f}^{p}+2\tilde{f}f_{f}^{m}+\tilde{f}f_{f}^{o}\right)/4\right)\right) \qquad (3.35)
\end{aligned}
$$

$$\begin{aligned}
\text{Min} z_2 = & \sum_{\forall l}\sum_{\forall i}\sum_{\forall j}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_1^p + 2\tilde{\theta}_1^m + \tilde{\theta}_1^o}{4}\right)\cdot \text{TRS}_{ijt}^l\right) \\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall j}\sum_{\forall k}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_2^p + 2\tilde{\theta}_2^m + \tilde{\theta}_2^o}{4}\right)\cdot \text{TPP}_{rjkt}^l\right) \\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall c}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_3^p + 2\tilde{\theta}_3^m + \tilde{\theta}_3^o}{4}\right)\cdot \text{TPD}_{rkct}^l\right) \\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall c}\sum_{\forall k}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_4^p + 2\tilde{\theta}_4^m + \tilde{\theta}_4^o}{4}\right)\cdot \text{TPC}_{rckt}^l\right) \\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall j}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_5^p + 2\tilde{\theta}_5^m + \tilde{\theta}_5^o}{4}\right)\cdot \text{TPr}_{rkjt}^l\right) \\
& + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\sum_{\forall f}\sum_{\forall t}\left(\left(\frac{\tilde{\theta}_6^p + 2\tilde{\theta}_6^m + \tilde{\theta}_6^o}{4}\right)\cdot \text{TP}f_{rkft}^l\right) \qquad (3.36)
\end{aligned}$$

$$\text{Max}\, z_3 = \sum_{\forall l}\sum_{\forall r}\sum_{\forall t}\frac{\sum_{\forall j}\dfrac{\sum_{\forall i}\left(\left(\left(R\tilde{I}_i^p + 2R\tilde{I}_i^m + R\tilde{I}_i^o\right)/4\right)\text{TRS}_{ijt}^l\right)}{ur_r}}{\sum_{\forall c}\left(de\tilde{m}_{rct}^p + 2de\tilde{m}_{rct}^m + de\tilde{m}_{rct}^o\right)/4} \qquad (3.37)$$

$$\sum_{\forall l}\sum_{\forall j}\text{TRS}_{ijt}^l = \text{SR}_{it} \quad \forall i,t \qquad (3.38)$$

$$\sum_{\forall l}\sum_{\forall k}\text{TPP}_{rjkt}^l = \text{SP}_{rjt} \quad \forall r,j,t \qquad (3.39)$$

$$\sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\left(\text{TPP}_{rjkt}^l\cdot ur_r\right) = \sum_{\forall l}\sum_{\forall i}\text{TRS}_{ijt}^l + \sum_{\forall l}\sum_{\forall r}\sum_{\forall k}\left(\text{TPr}_{rjkt}^l\cdot ur_r\right) \quad \forall j,t \qquad (3.40)$$

$$\text{SH}_{rct} - \text{SH}_{rc(t-1)} + \sum_{\forall l}\sum_{\forall k}\left(\text{TPD}_{rkct}^l\right) = \left[\frac{\alpha}{2}\frac{de\tilde{m}_{rct}^p + de\tilde{m}_{rct}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{de\tilde{m}_{rct}^o + de\tilde{m}_{rct}^m}{2}\right] \quad \forall r,c,t \qquad (3.41)$$

$$\begin{aligned}
\sum_{\forall l}\sum_{\forall k}\text{TPC}_{rckt}^l \geq & \left(\frac{\alpha}{2}\frac{de\tilde{m}_{rc(t-1)}^p + de\tilde{m}_{rc(t-1)}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{de\tilde{m}_{rc(t-1)}^o + de\tilde{m}_{rc(t-1)}^m}{2} - \text{SH}_{rc(t-1)}\right) \qquad (3.42) \\
& \times\left(\frac{\alpha}{2}\frac{R\tilde{T}^p + R\tilde{T}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{R\tilde{T}^o + R\tilde{T}^m}{2}\right) \quad \forall r,c,t
\end{aligned}$$

$$\begin{aligned}
\sum_{\forall l}\sum_{\forall k}\text{TPC}_{rckt}^l \leq & \left(\frac{\alpha}{2}\frac{de\tilde{m}_{rc(t-1)}^p + de\tilde{m}_{rc(t-1)}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{de\tilde{m}_{rc(t-1)}^o + de\tilde{m}_{rc(t-1)}^m}{2} - \text{SH}_{rc(t-1)}\right) \qquad (3.43) \\
& \times\left(\frac{\alpha}{2}\frac{R\tilde{T}^p + R\tilde{T}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{R\tilde{T}^o + R\tilde{T}^m}{2}\right) \quad \forall r,c,t
\end{aligned}$$

$$\sum_{\forall l}\sum_{\forall j}\text{TPr}_{rkjt}^l \geq \left(\frac{\alpha}{2}\frac{R\tilde{R}^p + R\tilde{R}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{R\tilde{R}^o + R\tilde{R}^m}{2}\cdot\sum_{\forall l}\sum_{\forall c}\text{TPC}_{rkct}^l\right) \quad \forall r,k,t \qquad (3.44)$$

$$\sum_{\forall l}\sum_{\forall j}\text{TPr}_{rkjt}^l \leq \left(\frac{\alpha}{2}\frac{R\tilde{R}^p + R\tilde{R}^m}{2} + \left(1-\frac{\alpha}{2}\right)\frac{R\tilde{R}^o + R\tilde{R}^m}{2}\cdot\sum_{\forall l}\sum_{\forall c}\text{TPC}_{rkct}^l\right) \quad \forall r,k,t \qquad (3.45)$$

$$\sum_{\forall l}\sum_{\forall f}\mathrm{TP}f^{l}_{rkft}\le\left(\left(1-\frac{\alpha}{2}\frac{R\tilde{R}^{p}+R\tilde{R}^{m}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{R\tilde{R}^{o}+R\tilde{R}^{m}}{2}\right)\cdot\sum_{\forall l}\sum_{\forall c}\mathrm{TPC}^{l}_{rckt}\right)\quad\forall r,k,t \tag{3.46}$$

$$\sum_{\forall l}\sum_{\forall f}\mathrm{TP}f^{l}_{rkft}\le\left(\left(1-\frac{\alpha}{2}\frac{R\tilde{R}^{p}+R\tilde{R}^{m}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{R\tilde{R}^{o}+R\tilde{R}^{m}}{2}\right)\cdot\sum_{\forall l}\sum_{\forall c}\mathrm{TPC}^{l}_{rckt}\right)\quad\forall r,k,t \tag{3.47}$$

$$\sum_{\forall l}\sum_{\forall j}\mathrm{TPP}^{l}_{rjkt}-\mathrm{ID}_{rkt}+\mathrm{ID}_{rk(t-1)}=\sum_{\forall l}\sum_{\forall j}\mathrm{TPD}^{l}_{rkct}\quad\forall r,k,t \tag{3.48}$$

$$\sum_{\forall r}\left(\mathrm{ID}_{rkt}\cdot\left(\alpha\frac{v\tilde{r}^{o}+v\tilde{r}^{m}}{2}+(1-\alpha)\frac{v\tilde{r}^{p}+v\tilde{r}^{m}}{2}\right)\right)\le\left(\alpha\frac{ca\tilde{p}d^{o}_{k}+ca\tilde{p}d^{m}_{k}}{2}+(1-\alpha)\frac{ca\tilde{p}d^{p}_{k}+ca\tilde{p}d^{m}_{k}}{2}\right)\quad\forall k,t \tag{3.49}$$

$$\left(\left(\alpha\frac{v\tilde{r}^{o}+v\tilde{r}^{m}}{2}+(1-\alpha)\frac{v\tilde{r}^{p}+v\tilde{r}^{m}}{2}\right)\cdot\mathrm{TRS}^{l}_{ijt}\right)\le\left(\left(\alpha\frac{cap\tilde{l}^{p}_{k}+cap\tilde{l}^{m}_{k}}{2}+(1-\alpha)\frac{cap\tilde{l}^{o}_{k}+cap\tilde{l}^{m}_{k}}{2}\right)\cdot\mathrm{NS}^{l}_{ijt}\right)\quad\forall l,j,i,t \tag{3.50}$$

$$\sum_{\forall r}\left(\left(\alpha\frac{\tilde{v}^{o}_{r}+\tilde{v}^{m}_{r}}{2}+(1-\alpha)\frac{\tilde{v}^{p}_{r}+\tilde{v}^{m}_{r}}{2}\right)\cdot\mathrm{TPP}^{l}_{rjkt}\right)\le\left(\left(\alpha\frac{c\tilde{a}pl^{p}_{l}+c\tilde{a}pl^{m}_{l}}{2}+(1-\alpha)\frac{c\tilde{a}pl^{o}_{l}+c\tilde{a}pl^{m}_{l}}{2}\right)\cdot\mathrm{NP}^{l}_{jkt}\right)\quad\forall l,j,k,t \tag{3.51}$$

$$\sum_{\forall r}\left(\left(\alpha\frac{\tilde{v}^{o}_{r}+\tilde{v}^{m}_{r}}{2}+(1-\alpha)\frac{\tilde{v}^{p}_{r}+\tilde{v}^{m}_{r}}{2}\right)\cdot\mathrm{TPD}^{l}_{rkct}\right)\le\left(\left(\alpha\frac{c\tilde{a}pl^{p}_{l}+c\tilde{a}pl^{m}_{l}}{2}+(1-\alpha)\frac{c\tilde{a}pl^{o}_{l}+c\tilde{a}pl^{m}_{l}}{2}\right)\cdot\mathrm{ND}^{l}_{kct}\right)\quad\forall l,k,c,t \tag{3.52}$$

$$\sum_{\forall r}\left(\left(\alpha\frac{\tilde{v}^{o}_{r}+\tilde{v}^{m}_{r}}{2}+(1-\alpha)\frac{\tilde{v}^{p}_{r}+\tilde{v}^{m}_{r}}{2}\right)\cdot\mathrm{TPC}^{l}_{cjkt}\right)\le\left(\left(\alpha\frac{c\tilde{a}pl^{p}_{l}+c\tilde{a}pl^{m}_{l}}{2}+(1-\alpha)\frac{c\tilde{a}pl^{o}_{l}+c\tilde{a}pl^{m}_{l}}{2}\right)\cdot\mathrm{NC}^{l}_{ckt}\right)\quad\forall l,c,k,t \tag{3.53}$$

$$\sum_{\forall r}\left(\left(\alpha\frac{\tilde{v}^{o}_{r}+\tilde{v}^{m}_{r}}{2}+(1-\alpha)\frac{\tilde{v}^{p}_{r}+\tilde{v}^{m}_{r}}{2}\right)\cdot\mathrm{TPr}^{l}_{rkjt}\right)\le\left(\left(\alpha\frac{c\tilde{a}pl^{p}_{l}+c\tilde{a}pl^{m}_{l}}{2}+(1-\alpha)\frac{c\tilde{a}pl^{o}_{l}+c\tilde{a}pl^{m}_{l}}{2}\right)\cdot\mathrm{NN}^{l}_{kjt}\right)\quad\forall l,k,j,t \tag{3.54}$$

$$\sum_{\forall r}\left(\left(\alpha\frac{\tilde{v}^{o}_{r}+\tilde{v}^{m}_{r}}{2}+(1-\alpha)\frac{\tilde{v}^{p}_{r}+\tilde{v}^{m}_{r}}{2}\right)\cdot\mathrm{TP}f^{l}_{rkft}\right)\le\left(\left(\alpha\frac{c\tilde{a}pl^{p}_{l}+c\tilde{a}pl^{m}_{l}}{2}+(1-\alpha)\frac{c\tilde{a}pl^{o}_{l}+c\tilde{a}pl^{m}_{l}}{2}\right)\cdot\mathrm{NRK}^{l}_{kft}\right)\quad\forall l,k,f,t \tag{3.55}$$

$$\sum_{\forall l}\sum_{\forall j}\mathrm{TRS}^{l}_{ijt}\le\left(\alpha\frac{ca\tilde{p}I^{p}_{i}+ca\tilde{p}I^{m}_{i}}{2}+(1-\alpha)\frac{ca\tilde{p}I^{o}_{i}+ca\tilde{p}I^{m}_{i}}{2}\right)\quad\forall i,t \tag{3.56}$$

$$\sum_{\forall l}\sum_{\forall f}\mathrm{TR}f^{l}_{rkft}\le\left(\left(\alpha\frac{ca\tilde{p}f^{p}_{f}+ca\tilde{p}f^{m}_{f}}{2}+(1-\alpha)\frac{ca\tilde{p}f^{o}_{f}+ca\tilde{p}f^{m}_{f}}{2}\right)\cdot Z_{ft}\right)\quad\forall r,f,t \tag{3.57}$$

$$\sum_{\forall l}\sum_{\forall k}\mathrm{TPP}^l_{rjkt} \leq \left(\left(\alpha\frac{ca\tilde{p}p^p_j + ca\tilde{p}p^m_j}{2} + (1-\alpha)\,\frac{ca\tilde{p}p^o_j + ca\tilde{p}p^m_j}{2}\right)\cdot X_{rjt}\right) \quad \forall r,j,t \tag{3.58}$$

$$\sum_{\forall l}\sum_{\forall j}\mathrm{TPP}^l_{rjkt} \leq \left(\left(\alpha\frac{ca\tilde{p}d^p_k + ca\tilde{p}d^m_k}{2} + (1-\alpha)\,\frac{ca\tilde{p}d^o_k + ca\tilde{p}d^m_k}{2}\right)\cdot U_{ft}\right) \quad \forall r,k,t \tag{3.59}$$

$$\sum_{\forall l}\sum_{\forall c}\mathrm{TPD}^l_{rkct} \leq \left(\left(\alpha\frac{ca\tilde{p}d^p_k + ca\tilde{p}d^m_k}{2} + (1-\alpha)\,\frac{ca\tilde{p}d^o_k + ca\tilde{p}d^m_k}{2}\right)\cdot U_{ft}\right) \quad \forall r,k,t \tag{3.60}$$

$$\sum_{\forall l}\sum_{\forall i}\mathrm{TPr}^l_{rkjt} + \sum_{\forall l}\sum_{\forall f}\mathrm{TP}f^l_{rkft} \leq \left(\left(\alpha\frac{ca\tilde{p}d^p_k + ca\tilde{p}d^m_k}{2} + (1-\alpha)\,\frac{ca\tilde{p}d^o_k + ca\tilde{p}d^m_k}{2}\right)\cdot U_{ft}\right) \quad \forall r,k,t \tag{3.61}$$

$$\sum_{\forall l}\sum_{\forall c}\mathrm{TPC}^l_{rckt} \leq \left(\left(\alpha\frac{ca\tilde{p}dr^p_k + ca\tilde{p}dr^m_k}{2} + (1-\alpha)\,\frac{ca\tilde{p}dr^o_k + ca\tilde{p}dr^m_k}{2}\right)_k\cdot U_{ft}\right) \quad \forall r,k,t \tag{3.62}$$

$$\sum_{\forall l}\sum_{\forall k}\mathrm{TPr}^l_{rkjt} \leq \left(\left(\alpha\frac{ca\tilde{p}r^p_j + ca\tilde{p}r^m_j}{2} + (1-\alpha)\,\frac{ca\tilde{p}r^p_j + ca\tilde{p}r^m_j}{2}\right)\cdot X_{rjt}\right) \quad \forall r,j,t \tag{3.63}$$

$$\mathrm{SR}_{it}, \mathrm{SP}_{rjt}, \mathrm{ID}_{rkt}, \mathrm{TP}f^l_{rkft}, \mathrm{TRS}^l_{ijt}, \mathrm{TPK}^l_{rkj}, \mathrm{TPC}^l_{rckt}, \mathrm{TPD}^l_{rkct}, \mathrm{SH}_{rct}, \mathrm{TPP}^l_{rjkt} \geq 0 \tag{3.64}$$

$$\mathrm{NS}^l_{ijt}, \mathrm{NP}^l_{jkt}, \mathrm{ND}^l_{kct}, \mathrm{NC}^l_{ckt}, \mathrm{NN}^l_{ckt}, \mathrm{NRK}^l_{ck}, X_{rjt}, U_{ft}, Z_{ft} \in \{0,1\}\,.$$

4. Imperialist competitive algorithm

The imperialist competitive algorithm was first introduced by Atashpaz and Lucas [7]. Therefore, this algorithm, in the first place, with a completely new perspective on optimization, establishes a new link between the humanities and the social sciences on the one hand and the technical and mathematical sciences on the other. In particular, this algorithm looks at the process of imperialization as a stage in the socio-political development of mankind, and by mathematical modeling of this historical phenomenon, it is used as the source of inspiration for a powerful optimization algorithm. Also, it has been used to solve many problems in the area of optimization. In order to evaluate the efficiency of this algorithm, problems that with other evolutionary algorithms are solved with this the algorithm has been solved, which better results both in terms of time and in terms of optimal response [7].

This paper, Since the problem is NP-hard for solving the addressed problem, a new modified imperialist competitive algorithm (MICA) is proposed to obtain good solution results. This algorithm consists of a new assimilation policy (*i.e.*, colonies moving) and imperialistic competition procedure to balance between exploration and exploitation of the original ICA and improve its performances.

4.1. Imperialist competitive algorithm approach to solve a Green closed-loop supply chain network design problem

Colonial competition algorithm as with other evolutionary algorithms, this algorithm also begins with a number of random primitive populations, each of which is called a "country". Some of the best elements of the population (the equivalent of the elites in the genetic algorithm and particle in the overcrowding of particles) are chosen as imperialists. The remainder of the population is considered as colonial. Depending on their power, the colonialists take their colonies with a specific process that goes on. The power of the whole empire depends on both its constituent parts, the imperialist state (as the core) and its members. In mathematical terms, this dependence is modeled by defining the power of the empire as the sum of imperialist state power, plus a percentage of its average colonial power. With the formation of the early empires, imperial competition between them begins. Every empire that fails in colonial competition, it will succeed and add to its power (or at least minimize its influence), will be eliminated from the scene of colonial competition. Therefore, the survival of an empire will depend on its power to capture the competing empires and to dominate them. As a result, during the imperialist rivalries, too gradually, the power of the larger empires and the weaker empires will be eliminated. Empires in order to increase their power, they will have to advance their colonies. Over time, the colonies, in terms of power, the empires will be closer and we will see a kind of convergence. The ultimate limit of colonial competition is when we have a single empire in the world, with pensions that are in terms of position, Imperial countries are very close. In the next section of this section, different sections of the algorithm are presented [7].

The original steps of ICA, firstly proposed as follows.

Start ICA

1. Initialize the empires.
2. Move the colonies toward their relevant imperialist (*i.e.*, assimilating).
3. If there is a colony in an empire which has lower cost than that of imperialist, exchange the positions of that colony and the imperialist.
4. Compute the total cost of all empires.
5. Pick the weakest colony from the weakest empire and give it to the empire that has the most likelihood to possess it.
6. Eliminate the empire that has no colonies.
7. If the stopping criteria met, stop the algorithm; if not, go to step 2.

End ICA

In this paper, we use the basic idea and steps of the above-mentioned ICA for the problem. Therefore, we propose and utilize some novel ideas detailed in the following steps.

4.2. Formation initial empires

Generally, in optimization, the goal is to find an optimal answer in terms of the problem variables. We create an array of problem variables that need to be optimized. Here, we call it a country. In a N_{var} subsequent optimization problem, a country is an array $1 \times N_{\text{var}}$. This array is defined as (4.1).

$$\text{Country} = [p_1, p_2, p_3, \ldots, p_{N_{\text{var}}}] . \tag{4.1}$$

The values of variables in a country are represented as decimal numbers. In fact, in solving an optimization problem by the algorithm, we are looking for the best country (the country with the best social-political features). Finding this country is in fact equivalent to finding the best parameters of the problem that produces the least amount of the cost function.

To start the algorithm, there must be a number of these countries (the number of countries in the initial algorithm). Therefore, the matrix of all countries is formed randomly as (4.2).

$$\text{Country} = \begin{bmatrix} \text{country}_1 \\ \text{country}_2 \\ \text{country}_3 \\ \vdots \\ \text{country}_{N_{\text{country}}} \end{bmatrix} . \tag{4.2}$$

The cost of a country can be found by evaluating the function f in variables $(p_1, p_2, p_3, \ldots, p_{N_{\text{var}}})$ Therefore:

$$\cos t_i = f\left(\text{country}_i\right) = f\left(p_1, p_2, p_3, \ldots, p_{N_{\text{var}}}\right) . \tag{4.3}$$

The algorithm introduced in this paper, by generating an initial set of answers and categorizing them in the form of empires and applying the policy of absorbing colonialists from the colonies and also by creating a colonial competition between the empires, they seek the best of the country.

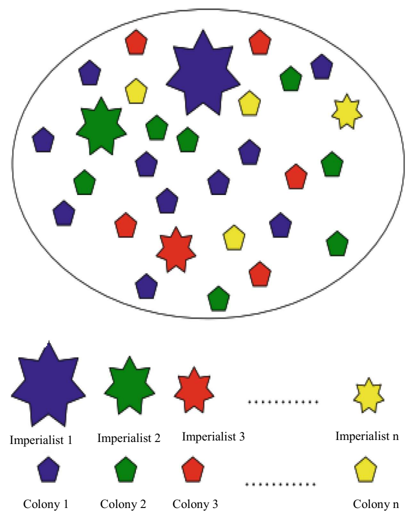

FIGURE 2. Generating the initial empires.

Also, to start the algorithm, we create the number of N_{country} the primary country. We select N_{imp} the best members of this population (the countries with the least amount of cost function) as imperialists. The remaining N_{col} from the countries form colonies, each of which belongs to an empire. To divide the initial colonies between the imperialists, we give each imperialist number of colonies that this number corresponds to its strength. Therefore, with the cost of all imperialists, we consider their normalization costs as follows:

$$c_n = \max\{c_i\} - c_n. \tag{4.4}$$

From another perspective, the normalized power of an imperialist, the colonial ratio is run by the imperialist. Also, the initial number of colonies an imperialist will be equal to:

$$N{\cdot}C_n = round\{p_n \cdot (N_{\text{col}})\} \tag{4.5}$$

where, $N{\cdot}C_n$ is the number of primary empires of the colonies and N_{col} is the total number of colonial countries in the population of the primary countries. *round* is the function that gives the closest integer to a decimal number. Given $N{\cdot}C_n$ for each empire, We will randomly select the initial colonial countries and give our n imperialists. Also, with the initial state of all empires, begins the imperialist competition algorithm. The evolution process is in a loop that continues until a stop condition is fulfilled.

Figure 2 shows the initial population of each empire. As depicted, the bigger an empire is, the greater number of colonies it has. In this figure, imperialist 1 has formed the most powerful empire and has the greatest number of colonies.

4.3. Moving the colonies of an empire toward the imperialist (assimilating)

The policy of assimilation was to analyze the culture and social structure of the colonies in the culture of the central government. As already stated, colonial countries began to build civilization (to build transport infrastructure, establish a university, etc.) to increase their influence. This part of the colonial process of optimization algorithm is modeled as the movement of colonies towards the imperialist country. Figure 3 illustrates the general schema of this move [7].

As shown in this figure, the colonial country size x unit moved in the direction of the colonial to imperialist, and is drawn to a new position. In this figure, the distance between the imperialist and the colony is shown

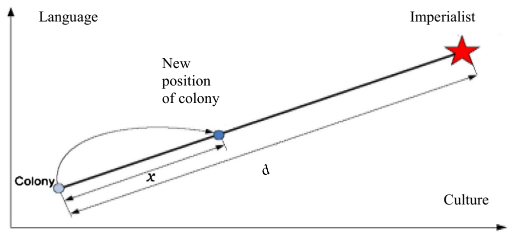

Figure 3. The general scheme of the movement of the colonials towards the imperialist.

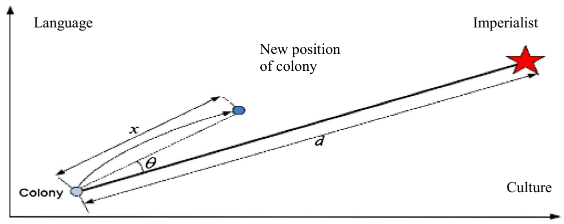

Figure 4. The actual movement of the colonies towards the imperialist.

with d. x is also a random number with a uniform distribution (or any other suitable distribution). Also, we have for x:

$$x \cong U\left(0, \beta \times d\right) \tag{4.6}$$

where β is a number larger than 1 and close to 2. Also, an appropriate choice can be $\beta = 2$. Therefore, the existence of the coefficient $\beta > 1$ causes the colonial country moves towards the colonial country in different directions.

In other hand, with the historical analysis of the phenomenon of assimilation, one obvious fact in this regard is that, despite the fact that the colonial countries were actively pursuing an assimilation policy, but the events did not fully follow the policies they applied, and there were deviations from the result of the work. In the proposed algorithm, this probable deviation is accomplished by adding a random angle to the assimilation colonial path. To this end, in moving the colonies towards the imperialist, we add a little bit of a random angle to the colonial movement. Figure 4 shows this mode. For this purpose, this time, instead of moving x, towards the colonial country, and in the direction of the vector of the colonial to imperialist, we continue to move the same, but with a deviation θ on the path. We consider θ as randomly and uniformly. So:

$$\theta \approx U\left(-\gamma, \gamma\right). \tag{4.7}$$

In equation (4.7), γ is an arbitrary parameter, which increases makes the search for the surrounding imperialists, and the reduction also makes the colonies move as close as possible to the colonial to imperialist vector. Considering the radian unit for γ, a number close to $\pi/4$, in most implementations, was a good choice [7].

4.4. Moving positions of the imperialist and a colony

In the modeling of this historical event, the algorithm has been introduced to this effect as colonies move towards a colonial country, some of these colonies may reach a better position than the imperialist (to points in the cost function that generate less cost than the value of the cost function in the imperialist position). In this case, the colonial country and the colony country changed their place together and the algorithm with the colonial country continued in a new position, this time this new imperialist country, which began to apply a policy of assimilation on its colonies [12].

4.5. Total power of an empire

The power of an empire equals the power of the colonial country, plus a percentage of the power of its colonies. Thus, for the total cost of an empire, we have:

$$T{\cdot}c_n = \text{Cost}\left(\text{imperialist}_n\right) + \xi \,\text{mean}\left\{\cos t\left(\text{colonies of empire}_n\right)\right\} \tag{4.8}$$

where $T{\cdot}c_n$ is the total cost of the nth empire and ξ is a positive number considered to be less than 1. A little value for ξ causes the total cost of the empire to be determined by just the imperialist, and increasing it will increase the role of the colonies in determining the total power of an empire. In this case, a type $\xi = 0.05$ has led to satisfactory answers in most implementations.

4.6. Imperialist competition

As previously stated, any empire that cannot add to its power and lose its competitive power, during imperialist competitions, it will be eliminated. This deletion is done gradually. This means that, over time, the weak empires lost their colonies, and the stronger empires possession these colonies and add to their power. To model this fact, we assume that the empire being removed is the weakest empire available. In this way, in repeating the algorithm, one or more of the weakest colonies of the weakest empire is taken out and for the capture of these colonies, we create a competing among all the empires. These colonies, not necessarily taken by the strongest empire, but stronger empires are more likely to be possession. To do this, we first set the normalized total cost of the total cost of the empire:

$$N \cdot T \cdot C_n = \max_i \left\{T \cdot C_i\right\} - T \cdot C_n \tag{4.9}$$

where $T \cdot C_n$ and $N \cdot T \cdot C_n$ are the total cost and normalized total cost of the nth empire, respectively. Also, each Empire, which has $T \cdot C_n$ smaller number, will have $N \cdot T \cdot C_n$ more. In fact, $T \cdot C_n$ is the equivalent of the total cost of an empire, and $N \cdot T \cdot C_n$ equal to its total power. Imperialist with the least cost has the most power.

Therefore, with the normalized total cost, the probability (power) of colonial possession of competition, by each empire, is calculated as follows:

$$P_{p_n} = \left|\frac{N \cdot T \cdot C_n}{\sum_{i=1}^{N_{\text{imp}}} N \cdot T \cdot C_n}\right|. \tag{4.10}$$

With the possibility of possession each empire, for the mentioned colonies to be randomized, but with the probability of being depended on to possession each empire probability, we divide the mentioned colonies between empires; The vector P on the above probability values, is formed as the follows:

$$P = \left[P_{p_1}, P_{p_2}, P_{p_3}, \ldots, P_{p_{N_{\text{imp}}}}\right]. \tag{4.11}$$

The vector P has a size of $1 * N_{\text{imp}}$ and is comprised of the possession probability values of the empires. Then, the vector r, whose elements are uniformly distributed random numbers, is created with the same size as P.

$$R = \left[r_1, r_2, r_3, \ldots, r_{N_{\text{imp}}}\right] \tag{4.12}$$

$$r_1, r_2, r_3, \ldots, r_{N_{\text{imp}}} \approx U\left(0, 1\right). \tag{4.13}$$

The vector D is formed as follows:

$$D = P - R = \left[D_1, D_2, D_3, \ldots, D_{N_{\text{imp}}}\right] \tag{4.14}$$

$$= \left[P_{p_1} - r_1, P_{p_2} - r_2, P_{p_3} - r_3, \ldots, P_{p_{N_{\text{imp}}}} - r_{N_{\text{imp}}}\right] \tag{4.15}$$

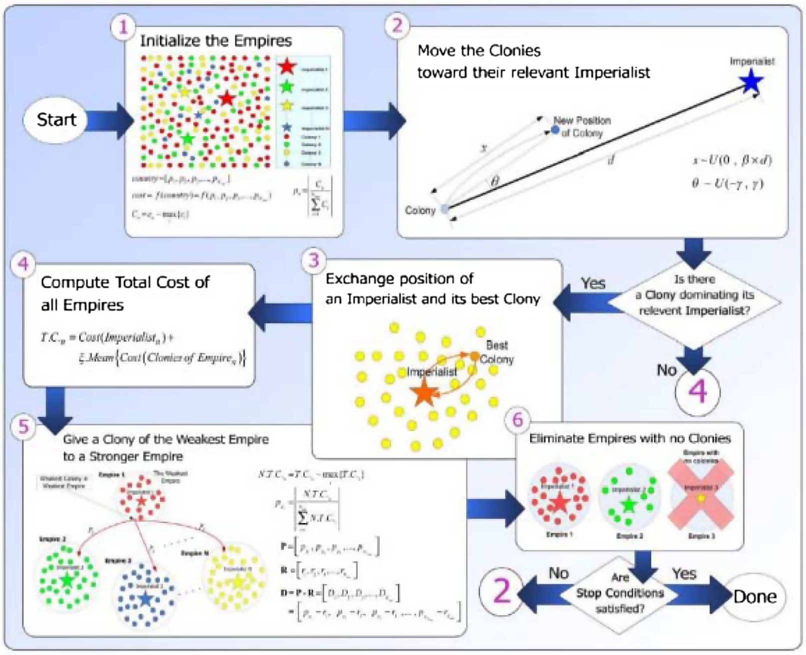

FIGURE 5. The general schema of the imperialist competitive algorithm.

vector D, we give the mentioned colonies to an empire, which index is related to vector D is larger than the other. The empire that has the most probability of possession most likely, the index is related to vector D will have the highest value. In addition, with colonial possession by one of the empires, the operation of this phase of the algorithm ends [7].

4.7. The collapse of weak empires

The collapse of weak empires Different conditions can be considered for the collapse of an empire. In the proposed algorithm, an empire is removed when its colonies are lost [14].

4.8. Convergence

The algorithm continues until a convergence condition is fulfilled, or until the completion of the total number of repetitions. After a while, all empires will collapse, and we will have only one empire, and the rest of the countries is under the control of this unit empire. In this new ideal world, all colonies, by a unit empire are managed and the colonial positions and costs are equal to the position and cost of the imperialist state. In this new world, there is no difference, not only between the colonies, but between the colonies and the imperialist countries. In other words, all countries, at the same time, are colonies and colonialists. In such a situation, the imperial competition is over and it stops as one of the conditions for stopping the algorithm. The general schema of the algorithm is graphically depicted in Figure 5. According to this figure, the algorithm begins with the random initial population and the generation of initial empires and is repeated in a cycle of assimilating policy and imperialist competition [1,13].

TABLE 2. Size and level of problems.

Problem levels	Problem size (I, J, K, C, F, R, T, L)
Small scale	1 (8, 4, 2, 8, 12, 8, 2, 3)
	2 (10, 6, 2, 10, 16, 3, 3)
	3 (12, 5, 2, 9,17, 4, 3, 5)
Medium scale	4 (18, 7, 4, 8, 12, 8, 2, 3)
	5 (20, 9, 4, 10, 16, 3, 3)
	6 (27, 11, 4, 9,17, 4, 3, 5)
Large scale	7 (32, 14, 6, 8, 12, 8, 2, 3)
	8 (37, 18, 6, 10, 16, 3, 3)
	9 (40, 22, 6, 9,17, 4, 3, 5)

5. Computational experiments

5.1. Parameter setting

In this section, adjust the parameters of the modification imperialist competitive algorithms. In order to evaluate efficiency of the proposed algorithms, so will compare the model in several problems with different sizes, which different sizes of problem shows in Table 2.

The performance of proposed algorithms in each of the 9 problem samples is examined on a different parameter depending on the different values of each parameter. The results of the parameter setting tests are shown in Table 3.

To compare our algorithm and other solution approaches, some test problems are needed. To illustrate the effectiveness of the proposed model, a numerical example is presented in this section. In this example, there are three suppliers, four potential locations for manufacturing/re-manufacturing centers, four distribution/collection centers, two destruction centers, three types of transportation vehicles, five customers, and four time periods. Also, the model is solved in multi-product mode and considering three products. The parameters of the model are shown in Table 4. To obtain computational results, the model is computed in the GAMS software, using the CPLEX solver. All calculations are made using a computer with a Core i3.2.4 GHz processor with a 4.00 GB RAM of the operating system Windows 7 (64 bit). The results of these experiments and the exact solution obtained are shown in Table 5.

As can be seen in Figure 6, with increasing level α, the objective function Z_1 be decreased, that is, the costs have been reduced. The objective function Z_2 be increased, which means that with increased production, the released gases are also increased. The objective function Z_3 be decreased, which means with increasing the reliability of the system, it decreases. The multi-objective fuzzy TH approaches allow the decision maker to make the final decision by choosing the appropriate solution based on the degree of satisfaction and the priority of each objective function; these approaches are also capable of generating balanced and unbalanced responses according to the preference of the decision maker. Therefore, Figure 7 shows the membership functions obtained through the Torabi-Hessini method. After DE fuzzy, we obtain the objective functions of minimization from equation (3.32) and the objective functions of maximizing from equation (3.33) using this method. As the figure shows, with increasing levels α, membership functions $\mu(\mathrm{z}_1)$ be increased, membership functions $\mu(z_2)$ and $\mu(\mathrm{z}_3)$ be decreased.

Also, Figure 8 is shows compares the time between different levels α. As the levels α increase, the time to solve the objective functions and membership functions be increased.

Finally, it can be concluded that the TH approach is an appropriate and efficient approach to solving multi-objective MILP problems because it achieves effective solutions, but when the decision maker is more important

TABLE 3. Best level of parameters for GA, SA, ICA, ACO, PSO, and MICA algorithms.

Algorithm	Parameter	Parameter tuning combinations								
		1	2	3	4	5	6	7	8	9
GA	N_{Pop}	50	75	100	125	150	175	200	225	250
	P_c	0.25	0.5	0.75	1	1.25	1. 5	1.75	2	2.25
	P_m	1	3	5	6	6	7	8	8	10
	Max-iteration	50	100	150	200	250	300	350	400	450
	Total cost	1843	1834	1930	2015	2129	2494	2698	2745	3291
ACO	Number of ants	50	75	100	125	150	175	200	225	250
	Pheromone factor α	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	Heuristic factor β	2	3	4	5	6	7	8	9	10
	Evaporation rate ρ	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	Max-iteration	50	100	150	200	250	300	350	400	450
	Total cost	1800	1708	1870	2001	2011	2234	2341	2506	2990
SA	Max-iteration	50	100	150	200	250	300	350	400	450
	Sub-iteration	25	50	75	100	125	150	175	200	225
	Mutation	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	Initial temperature	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	Total cost	2031	2443	3054	3576	3883	4193	4815	5044	6111
PSO	C_1, C_2	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	W	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	W_{damp}	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
	N_{Pop}	50	100	150	200	250	300	350	400	450
	Max-iteration	50	100	150	200	250	300	350	400	450
	Total cost	1975	2077	2272	2676	3085	3584	3679	4170	4982
MICA	N_{Pop}	50	75	100	125	150	175	200	225	250
	Percentage of N_{imp}	0.25	0.5	0.75	1	1.25	1. 5	1.75	2	2.25
	A	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
	B	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6
	Total cost	1343	1434	1532	1796	1921	2093	2232	2545	2691
ICA	N_{Pop}	50	75	100	125	150	175	200	225	250
	Percentage of N_{imp}	0.25	0.5	0.75	1	1.25	1. 5	1.75	2	2.25
	Total cost	1743	1734	1632	1596	1521	1493	1432	1345	1291

to the minimum level of satisfaction of the objective functions, in other words to achieve more balanced solutions, TH method is a suitable method.

To analyze the interaction between the quality of the algorithms and different problem sizes, the total cost obtained by each algorithm are shown in Figure 9. As it can be seen, the MICA and the ICA keep their robust performance in all the problem sizes. In all the problem size, MICA has good results and better performance in comparison to even other algorithms. Therefore, in some sizes, MICA and ICA have been nearly competitive, but MICA has a superior performance in 7, 8 and 9 sizes. So, based on the results, we conclude that the proposed MICA and ICA can be used to effectively solve the green closed-loop supply chain network design problems. Moreover, as it can be seen in the results, the performance of the MICA shows that modifying the colonies moving and imperialistic competition improves the performance of the ICA remarkably.

6. Conclusions and future research directions

In this paper, we modeled a multi-objective mixed integer linear programming problem considering a multi-period, multi-product and multi-level under uncertainty green close-loop network chain network to minimize

TABLE 4. Parameters value.

Value	Parameter	Value	Parameter	Value	Parameter
$cap\tilde{d}r_k$	$\sim uniform(400, 900)$	$ft\tilde{d}^l_{kct}$	$\sim uniform(10, 35)$	$r\tilde{p}_{it}$	$\sim uniform(5, 15)$
$cap\tilde{f}_f$	$\sim uniform(300, 500)$	$\widetilde{vtd}^l_{rkct}$	$\sim uniform(5, 10)$	$de\tilde{m}_{rct}$	$\sim uniform(250, 800)$
$c\tilde{a}pl_l$	$\sim uniform(60, 120)$	$ft\tilde{d}^l_{kct}$	$\sim uniform(5, 20)$	$\tilde{f}_j$	$\sim uniform(5000, 8500)$
$R\tilde{F}$	$\sim uniform(0.5, 0.3)$	$vt\tilde{c}^l_{rckt}$	$\sim uniform(6, 12)$	$\tilde{f}k_{kt}$	$\sim uniform(4000, 8500)$
$\tilde{\theta}_1$	$\sim uniform(0.04, 0.1)$	$ft\tilde{r}^l_{kjt}$	$\sim uniform(15, 30)$	$\tilde{f}f_{ft}$	$\sim uniform(3000, 7000)$
$\tilde{\theta}_2$	$\sim uniform(0.04, 0.1)$	$vt\tilde{r}^l_{rkjt}$	$\sim uniform(5, 9)$	$p\tilde{c}_{rjt}$	$\sim uniform(10, 3)$
$\tilde{\theta}_3$	$\sim uniform(0.04, 0.1)$	$\tilde{f}tf^l_{kjt}$	$\sim uniform(10, 40)$	$p\tilde{c}r_{it}$	$\sim uniform(2, 9)$
$\tilde{\theta}_4$	$\sim uniform(0.04, 0.1)$	$vt\tilde{f}^l_{rkft}$	$\sim uniform(2, 9)$	$d\tilde{c}_{rft}$	$\sim uniform(5, 15)$
$\tilde{\theta}_5$	$\sim uniform(0.04, 0.1)$	$\tilde{v}_r$	$\sim uniform(0.5, 1.5)$	$h\tilde{c}_{rk}$	$\sim uniform(5, 10)$
$\tilde{\theta}_6$	$\sim uniform(0.04, 0.1)$	$v\tilde{r}$	$\sim uniform(0.5, 0.9)$	$sh\tilde{c}_{rc}$	$\sim uniform(1.5, 2.5)$
$s\tilde{t}_{rj}$	$\sim uniform(6, 20)$	$cap\tilde{p}_j$	$\sim uniform(400, 900)$	$ft\tilde{s}^l_{ijt}$	$\sim uniform(15, 25)$
$p\tilde{t}_{rj}$	$\sim uniform(20, 50)$	$cap\tilde{r}_j$	$\sim uniform(900, 1500)$	$vt\tilde{s}^l_{ijt}$	$\sim uniform(5, 10)$
$\max \tilde{f}_{jt}$	$\sim uniform(1500, 3000)$	$cap\tilde{I}_i$	$\sim uniform(3000, 4500)$	$ft\tilde{p}^l_{jkt}$	$\sim uniform(10, 40)$
$R\tilde{I}_t$	$\sim uniform(0.4, 0.8)$	$cap\tilde{d}_k$	$\sim uniform(400, 900)$	$vt\tilde{p}^l_{rjkt}$	$\sim uniform(4, 9)$

TABLE 5. Results computational $\gamma = 0/7$ and $\theta_1 = 0/6$, $\theta_2 = 0/2$, $\theta_3 = 0/2$.

TH method							
α_{level}	Z_1	Z_2	Z_3	$\mu(Z_1)$	$\mu(Z_2)$	$\mu(Z_3)$	CPU time (s)
0/6	1100608/357	3312/048	13/493	0/837	0/648	0/534	6/011
0/7	1092444/865	3300/702	13/149	0/848	0/658	0/508	61/498
0/8	1072577/905	3310/384	12/687	0/867	0/660	0/56	91/296
0/9	1056983/673	3383/874	12/12	0/885	0/653	0/554	26/713
1	1053252/869	3485/368	11/516	0/900	0/614	0/51	36/388

the total costs of the supply chain network, minimize the emission of gases resulting from vehicle displacement among the centers, and maximize the reliability of demand delivery with respect to the reliability defined for suppliers.

Also, two definitive two-step approaches have been used to solve this problem, and then, a novel fuzzy mathematical model was developed. To illustrate the efficiency of the proposed model, a numerical example is considered. Also, in order to obtain computational results, the proposed model in Gams software, and with using the CPLEX solver is calculated. The TH method is also used to solve the multi-objective model. Thus, considering the level α in the TH method, with increasing level α, the first and the third objective functions be decreased and the second objective function be increased. Also, with increasing the level α, the computational time, it has also been uptrend. Then, in order to adjust the parameters and operators of the proposed algorithms, the relevant parameters are tuned. The computational results show that the proposed MICA is capable of obtaining better solutions compared to the ICA, SA, PSO, GA, and ACO in all problem sizes.

In order to further work, we can propose exact solving methods for large-scale problem solving. Also, the proposed model in this paper can also be developed by considering several main decision makers in the closed-loop network and using the concept of the game theory. Also, other objective functions such as the power level of accountability, the minimum response time and the quality level of output products be added. can be considered in the model. therefore, to deal with the uncertainties in the chain, a robust programming can be used to make the proposed model more power and more flexible than uncertainty.

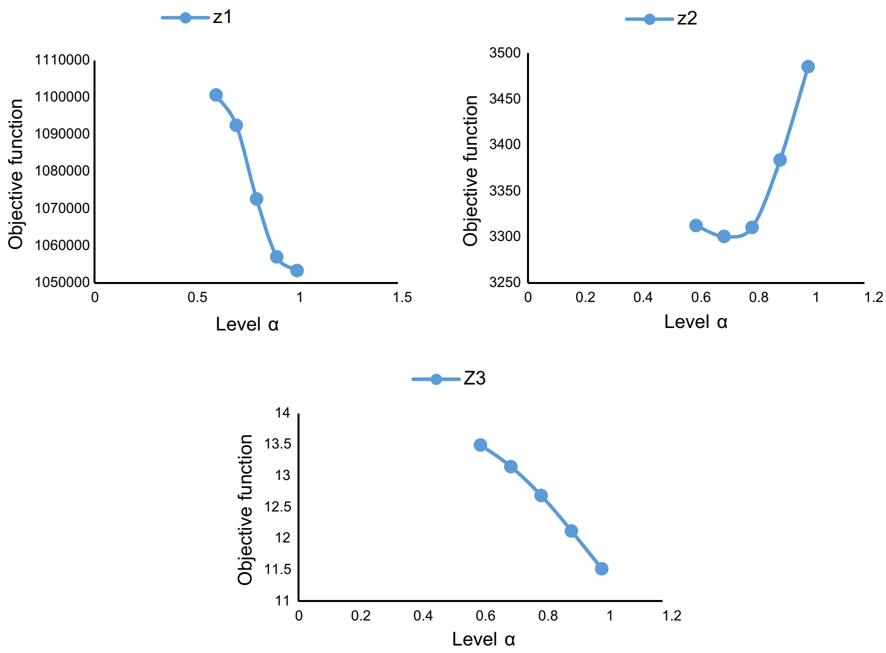

Figure 6. Objective functions obtained through TH method.

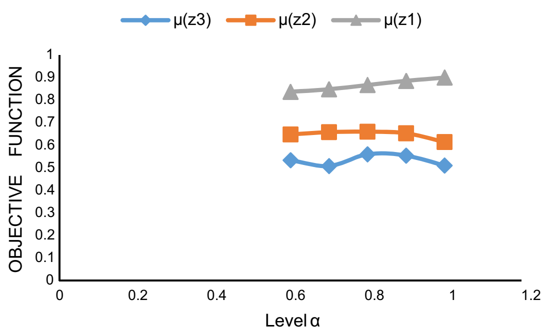

Figure 7. Objective functions through Torabi-Hessini method.

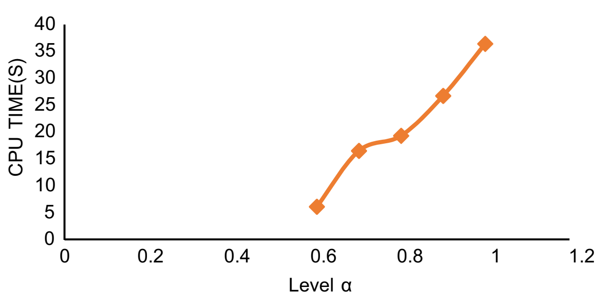

Figure 8. Comparison of time level α based on TH method.

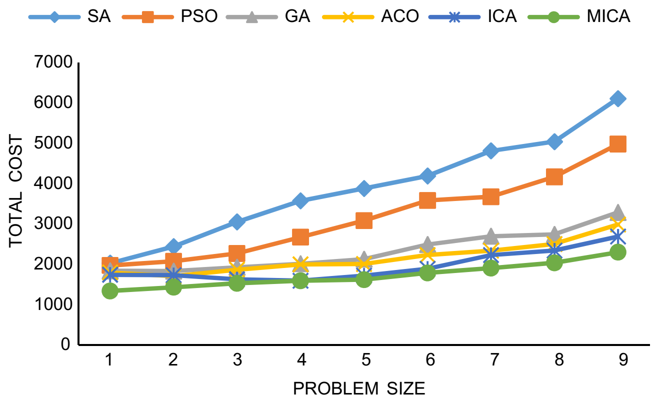

FIGURE 9. Total cost of parameters algorithms obtained among different sizes of problem.

REFERENCES

[1] N.S. Abarghoei, H. Hosaini-Nasab, M.B. Fakhrzad, Design of the evaluation model for total ergonomics interventions with fuzzy approach, *Sci. J. Pure Appl. Sci.* **1** (2012) 119–129.

[2] T. Abdallah, A. Farhat, A. Diabat and S. Kennedy, Green supply chains with carbon trading and environmental sourcing: Formulation and life cycle assessment. *Appl. Math. Modell.* **36** (2012) 4271–4285.

[3] M. Al-Salem, A. Diabat, D. Dalalah and M. Alrefaei, A closed-loop supply chain management problem: reformulation and piecewise linearization. *J. Manuf. Syst.* **40** (2016) 1–8.

[4] A. Alshamsi and A. Diabat, A reverse logistics network design. *J. Manuf. Syst.* **37** (2015) 589–598.

[5] S.H. Amin and F. Baki, A facility location model for global closed-loop supply chain network design. *Appl. Math. Modell.* **41** (2017) 316–330.

[6] S.H. Amin and G. Zhang, A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return. *Appl. Math. Modell.* **37** (2013) 4165–4176.

[7] E. Atashpaz-Gargari and C. Lucas, Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition. *IEEE Congr. Evol. Comput.* (2007) 4661–4667.

[8] C. Babbar and S.H. Amin, A multi-objective mathematical model integrating environmental concerns for supplier selection and order allocation based on fuzzy QFD in beverages industry. *Expert Syst. App.* **92** (2018) 27–38.

[9] H. Badri, S.F. Ghomi and T.H. Hejazi, A two-stage stochastic programming approach for value-based closed-loop supply chain network design. *Transp. Res. Part E: Logist. Transp. Rev.* **105** (2017) 1–17.

[10] E. Dehghan, M.S. Nikabadi, M. Amiri and A. Jabbarzadeh, Hybrid robust, stochastic and possibilistic programming for closed-loop supply chain network design. *Comput. Ind. Eng.* **123** (2018) 220–231.

[11] A. Diabat and R. Deskoores, A hybrid genetic algorithm based heuristic for an integrated supply chain problem. *J. Manuf. Syst.* **38** (2016) 172–180.

[12] A. Ebrahimy Zade and M.B. Fakhrzad, A dynamic genetic algorithm for solving a single machine scheduling problem with periodic maintenance. *ISRN Ind. Eng.* **21** (2013) 211–220.

[13] M.B. Fakhrzad and M. Heydari, A heuristic algorithm for hybrid flow-shop production scheduling to minimize the sum of the earliness ANDF tardiness costs. *J. Chin. Inst. Ind. Eng.* **25** (2008) 105–115.

[14] M.B. Fakhrzad and M. Moobed, A GA model development for decision making under reverse logistics. *Int. J. Ind. Eng. Prod. Res.* **21** (2010) 211–220.

[15] A.M. Fathollahi-Fard and M. Hajiaghaei-Keshteli, A stochastic multi-objective model for a closed-loop supply chain with environmental considerations. *Appl. Soft Comput.* **69** (2018) 232–249.

[16] A.M. Fathollahi-Fard, M. Hajiaghaei-Keshteli and S. Mirjalili, Hybrid optimizers to solve a tri-level programming model for a tire closed-loop supply chain network design problem. *Appl. Soft Comput.* **70** (2018) 701–722.

[17] M. Ghomi-Avili, S.G.J. Naeini, R. Tavakkoli-Moghaddam and A. Jabbarzadeh, A fuzzy pricing model for a green competitive closed-loop supply chain network design in the presence of disruptions. *J. Cleaner Prod.* **188** (2018) 425–442.

[18] A. Haddadsisakht and S.M. Ryan, Closed-loop supply chain network design with multiple transportation modes under stochastic demand and uncertain carbon tax. *Int. J. Prod. Econ.* **195** (2018) 118–131.

[19] A. Hiassat, A. Diabat and I. Rahwan, A genetic algorithm approach for locationinventory-routing problem with perishable products. *J. Manuf. Syst.* **42** (2017) 93–103.

[20] A. Jabbarzadeh, M. Haughton and A. Khosrojerdi, Closed-loop supply chain network design under disruption risks: A robust approach with real world application. *Comput. Ind. Eng.* **116** (2018) 178–191.

[21] R. Jerbia, M.K. Boujelben, M.A. Sehli and Z. Jemai, A stochastic closed-loop supply chain network design problem with multiple recovery options. *Comput. Ind. Eng.* **118** (2018) 23–32.
[22] M. Jimenez, M. Arenas, A. Bilbao and M.V. Guez, Linear programming with fuzzy parameters: an interactive method resolution. *Eur. J. Oper. Res.* **177** (2007) 1599–1609.
[23] O. Kaya and B. Urek, A mixed integer nonlinear programming model and heuristic solutions for location, inventory and pricing decisions in a closed loop supply chain. *Comput. Oper. Res.* **65** (2016) 93–103.
[24] M. Liu, R. Liu, Z. Zhu, C. Chu and X. Man, A bi-objective green closed loop supply chain design problem with uncertain demand. *Sustainability* **10** (2018) 967.
[25] H.A. Mahdiraji, S.H.R. Hajiagha, S.S. Hashemi and E.K. Zavadskas, Bi-objective mean–variance method based on Chebyshev inequality bounds for multi-objective stochastic problems. *RAIRO: OR* **52** (2018) 1201–1217.
[26] D.G. Mogale, M. Kumar, S.K. Kumar and M.K. Tiwari, Grain silo location-allocation problem with dwell time for optimization of food grain supply chain network. *Transp. Res. Part E: Logist. Transp. Rev.* **111** (2018) 40–69.
[27] K.P. Nurjanni, M.S. Carvalho and L. Costa, Green supply chain design: a mathematical modeling approach based on a multi-objective optimization model. *Int. J. Prod. Econ.* **183** (2017) 421–432.
[28] V. Özkır and H. Başlıgil, Multi-objective optimization of closed-loop supply chains in uncertain environment. *J. Cleaner Prod.* **41** (2013) 114–125.
[29] P. Peykani, E. Mohammadi, M.S. Pishvaee, M. Rostamy-Malkhalifeh and A. Jabbarzadeh, A novel fuzzy data envelopment analysis based on robust possibilistic programming: possibility, necessity and credibility-based approaches. *RAIRO: OR* **52** (2018) 1445–1463.
[30] H. Piroozfard, K.Y. Wong and W.P. Wong, Minimizing total carbon footprint and total late work criterion in flexible job shop scheduling by using an improved multi-objective genetic algorithm. *Res. Conserv. Recycl.* **128** (2018) 267–283.
[31] M.S. Pishvaee, K. Kianfar and B. Karimi, Reverse logistics network design using simulated annealing. *Int. J. Adv. Manuf. Technol.* **47** (2010) 269–281.
[32] M.S. Pishvaee, S.A. Torabi and J. Razmi, Credibility-based fuzzy mathematical programming model for green logistics design under uncertainty. *Comput. Ind. Eng.* **62** (2012) 624–632.
[33] R.S. Rad and N. Nahavandi, A novel multi-objective optimization model for integrated problem of green closed loop supply chain network design and quantity discount. *J. Cleaner Prod.* **196** (2018) 1549–1565.
[34] M. Ramezani, M. Bashiri and R. Tavakkoli-Moghaddam, A new multi-objective stochastic model for a forward/reverse logistic network design with responsiveness and quality level. *Appl. Math. Modell.* **37** (2013) 328–344.
[35] M. Ramezani, A.M. Kimiagari, B. Karimi and T.H. Hejazi, Closed-loop supply chain network design under a fuzzy environment. *Knowl.-Based Syst.* **59** (2014) 108–120.
[36] N. Sadra. Abarqhouei, H. Hosaini-Nasab, M.B. Fakhrzad, Macro ergonomics interventions and their impact on productivity and reduction of musculoskeletal disorders: including a case study. *Iran Occup. Health* **9** (2012) 27–39.
[37] N. Sahebjamnia, F. Goodarzian and M. Hajiaghaei-Keshteli, Optimization of multi-period three-echelon citrussupply chain problem. *J. Optim. Ind. Eng.* (2019) 41–50.
[38] K. Sari, A novel multi-criteria decision framework for evaluating green supply chain management practices. *Comput. Ind. Eng.* **105** (2017) 338–347.
[39] A.A. Shojaie and H. Raoofpanah, Solving a two-objective green transportation problem by using meta-heuristic methods under uncertain fuzzy approach. *J. Intell. Fuzzy Syst.* **34** (2018) 1–10.
[40] T.S. Su, Fuzzy multi-objective recoverable remanufacturing planning decisions involving multiple components and multiple machines. *Comput. Ind. Eng.* **72** (2014) 72–83.
[41] M. Talaei, B.F. Moghaddam, M.S. Pishvaee, A. Bozorgi-Amiri and S. Gholamnejad, A robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem: a numerical illustration in electronics industry. *J. Cleaner Prod.* **113** (2016) 662–673.
[42] S.A. Torabi and E. Hassini, An interactive possibilistic programming approach for multiple objective supply chain master planning. *Fuzzy Sets Syst.* **159** (2008) 193–214
[43] B.M. Tosarkani and S.H. Amin, A possibilistic solution to configure a battery closed-loop supply chain: Multi-objective approach. *Expert Syst. App.* **92** (2018) 12–26.
[44] Y.C. Tsao, V.V. Thanh, J.C. Lu and V. Yu, Designing sustainable supply chain networks under uncertain environments: fuzzy multi-objective programming. *J. Cleaner Prod.* **174** (2018) 1550–1565.
[45] M.L. Tseng, M. Lim, K.J. Wu, L. Zhou and D.T.D. Bui, A novel approach for enhancing green supply chain management using converged interval-valued triangular fuzzy numbers-grey relation analysis. *Res. Conserv. Recycl.* **128** (2018) 122–133.
[46] A. Yildizbaşi, A. Çalik, T. Paksoy, R.Z. Farahani and G.W. Weber, Multi-level optimization of an automotive closed-loop supply chain network with interactive fuzzy programming approaches. *Technol. Econ. Dev. Econ.* **24** (2018) 1004–1028.