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A Fuzzy Multi-Objective Model for Green Closed-Loop Supply Chain Network Design with Transshipment

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Abstract

This paper is on designs a green closed-loop supply chain network considering economic factors and environmental concerns and interconnected facilities. Over or under-achievement of forecasted supply, demand, and return, caused by the isolation of manufacturing and remanufacturing facilities (MRFs), can be compensated through lateral transshipment between MRFs. The decision variables are opening MRFs, environmental investment level for adopting clean technology in each MRF which is defined by linguistic variables, and the flow of products between nodes. Environmental investment and selection of transportation modes play important roles in the concerned objectives. A fuzzy multi-objective mathematical programming model is proposed for the problem under inherent uncertainty of supply, demand, returns, costs, capacities in the network, imprecise Co2 emission of transportation modes, and technology level. Solving two numerical examples shows the applicability of the model in the real world with the selected best technological level of MRFs and the reduction of costs and Co2 emission.

Keywords
Green closed-loop supply chain network design, Fuzzy multi-objective optimization, Transshipment, Transportation mode, Carbon emission.

1. Introduction
The design of a closed-loop supply chain network is an important issue that involves the determination of both sites and levels of operation which include a network of supplier, manufacturer, and distribution centers in forward flow, collection and inspection, and disposal in reverse flow with efficiently considering the connection between them to customer satisfaction (Salehi-Amiri et al 2022).

Environmental pollution should be addressed in supply chain management. Production activities and transport are the main sources of pollution and Co2 emission consequently causing global warming and harmful influences on the ecosystem and human health (Yu et al 2021, and Liu et al 2021). Designing a green supply chain network with proper transportation modes and environmental production technology can reduce greenhouse gas emissions and environmental pollution. Therefore, most countries have set strict plans to reduce their carbon emissions by change in the design of the supply chain network (Wang et al 2011). Also, green network design can strong brand image and consequently improve market share (Tseng et al 2019).

In this paper, we consider a single period, three-echelon forward logistic network, a two-echelon backward logistic network consisting of supplier, manufacturing and remanufacturing facility (MRF), customer zones, collection and inspection centers (CI), and disposal center.

In this model the stocks used by the manufacturers are supplied from several suppliers with identical quality; furthermore, the manufacturers also seek aid from the returned products for supplying the initial parts, which embraces advantages for the manufacturer in two ways: **1**) Considering the closed loop in the chain and using the returned materials; and 2) The closed loop can play the role of a reliable supplier in the network so that in case of fluctuations in the supply amount by the main suppliers of the supply chain network, it would be possible to mitigate the uncertainties and the negative fluctuations' impact using the returned products. The main aim of this research is to present a model for choosing a clean technology suitable for production technology investment and determining the cleanest transportation modes and planning for allocating the transportation mode capacity in the network.

Therefore, considering the importance of considering lateral transshipment, which is expected to reduce costs and CO_2 emissions, in order to cover the hidden gap in the literature, the following innovations have been attempted by this article.

•Applying the complete pooling strategy for lateral transshipment between MRFs.
•Reprocessing the recoverable products from collection and inspection centers.
•Paying attention to the different modes of MRF production technology and transportation from the point of emission
•Using the fuzzy concept in the main parameters of the problem along with the possible theory in soft constraints to deal with the uncertainty in the model.

The paper is organized as follows: Section 2 describes the assumptions and definitions of the proposed model. In Section 3, solving approach is explained. Our conclusion is given in the final Section.

A lot of works in the green supply chain network design are modeled in recent years, but decision makings in the strategic phase are considered in a few studies, Wang et al (2011), consider two conflicting goals including the cost of supply chain network and minimizing environmental pollution by reducing Co_2 emission in the forward network. The definition of pollution in this model restricts Co_2 emission. Also, the Co_2 emission in each process of the whole network is affected by environmental investment in production technology and the selection of transportation modes. In this paper, we allow lateral transshipment between facilities. This means that moving stock or products between facilities at the same echelon level of a supply chain is permitted (Lee et al 2007). Emergency lateral transshipment (ELT) and preventive lateral transshipment (PLT) are two ways for lateral transshipment. ELT is emergency redistribution for lack of product to cope with the shortage in facilities and PLT anticipates shortage before the realization of customer demands to reduce the risk of future stockout (Chen et al 2021).

Our model considers ELT to prevent isolating facilities from each other and consequently decrease the impact of uncertain demand and capacity. Although transportation cost is increased, lateral transshipment is known as a better approach than a policy of no transshipments (Xu and Szmerekovsky 2023). On the other hand, isolating facilities from each other causes a great drawback because of uncertainties in the demands and capacities of allocated facilities that lead to lost sales and decrease trust and loyalty of customers. Notably, assuming allowable transshipment between facilities can decrease environmental pollution by increasing alternatives of transportation modes.

2. Literature Review

Here we review the main relevant papers about the green closed-loop supply chain network design with transshipment. Zhen et al (2019) consider the supply chain network with uncertain demand via a bi-objective optimization model with two objectives of CO_2 emission and the objective of reducing operating costs. Environmental factors such as CO_2 emissions from transportation and CO_2 emissions from facilities are considered in their model. Their results show that both parameters have critical ratios that can cause significant changes in cost and CO_2 emissions.

Polo et al (2019) designed a closed-loop supply chain, taking into account the uncertainty of demand for final products in a multi-period model. In their model, the reverse flow of some products that must either be reprocessed or referred to the disposal center was considered. In their model, several MRFs, CIs, customer zones, and products were considered in a mixed integer non-linear programming single-objective model. Nayeri et al (2020) presented a multi-objective mathematical model to configure a sustainable closed-loop supply chain (SCLSC) network for a water reservoir considering financial, environmental, and social objectives. They used a fuzzy robust model to deal with subject uncertainty. In their study, different modes of transportation and carbon volume policy were considered along with other main variables of the supply chain network design problem. Ghahremani-Nahr et al (2019) attempt to propose a location/facility allocation model for a multi-period multi-layered multi-product network in the condition of shortage, uncertainty, and discount in the purchase of raw materials with the assumption of reversibility of materials using a robust fuzzy mixed integer nonlinear programming model. MINLP) which is able to reduce the total network costs. Their main innovation was on improving the method of solving the problem and the accuracy of the desired answer. Shabbier et al (2021) present a new closed-loop supply chain under uncertainty using the dimensions of resilience, stability, and reliability in the first studies. Their proposed model aims to minimize total cost, environmental pollution, and energy consumption while maximizing employment opportunities as a social factor and was able to achieve improvements in total cost, CO2 emissions, employment opportunities, and energy consumption.

Mehrjedi and Shafiei (2021) investigated the two concepts of resilience and sustainability in a closed-loop supply chain with the aim of simultaneously optimizing cost and resources, including human and environmental resources, to face possible risks. By identifying resilience criteria, they investigated the effects of supply chain strategies on resilience criteria using experts' opinions. Next, they investigated information sharing and multiple sourcing as two strategies in a multi-objective mixed integer programming model. Their results indicated the advantage of using strategies in reducing total cost, energy consumption, and pollution and increase job opportunities.

Most of the research in location inventory systems and production plans considered lateral transshipment as a method for satisfying uncertain demand (Bassey and Zelibe 2022). Wang et al (2021) consider uncertainty in disasters, focusing on lateral transportation opportunities for relief chains. He proposes a two-stage stochastic planning model to decide on the location of relief facilities and the allocation of relief resources simultaneously. Their results reveal that lateral transportation is more cost-effective and flexible than the direct transport solution.

The summary of the literature review shows that the uncertain nature of logistics network design parameters is an important issue, especially when environmental, social, and economic measures are considered.

In order to deal with the model, we consider demand, the capacity of facilities, and the costs of the network as triangular fuzzy variables. Also in our model, we introduce environmental investment decisions as fuzzy linguistic variables. Since of considering strategic decision-making in this paper and technology selection as objective, the advantages of the fuzzy approach in our model are: 1) Covering objective data (based on past observations) and subjective data (derived from the expert opinion) for decision-making problem; 2) Solving and making the definitive model easily; 3) Plan enough flexibility to answer different phase in data-fuzzy tolerance is calculated based on the decisions taken to decide the final answer; 4) The final answer fuzzy programming models with fewer calculations than are obtained using stochastic programming. In order to solve the model we present a fuzzy multi-objective mixed integer linear programming (FMOMILP) model to choose the potential suppliers from suppliers set to MRF, allocate each customer zone to MRF, and decide which facility to open, and finally how to distribute the products (flow of routes) with considering uncertainty demand, supply, cost, capacity, and environmental parameters. Nevertheless, in this study MRFs have been considered who provide the market with their products. The assumption is that they collaborate with each other and the assembly parts circulate among them (lateral transshipment) so that the potential and unpredicted shortages in a production period are met.

3. Methods

The main features of the developed five-echelon model and the relevant mathematical model of the paper are presented in this section. The developed model contains five echelons that are connected to each other with three types of transportation modes (rail, road, and air). The five echelons are, set of suppliers (S), manufacturing and remanufacturing facilities (MRF), customer zones (C), Collection and Inspection center (CI), and Disposal zone (DZ). It is notable, there is lateral transshipment between MRF at each echelon, see Figure 1. In the following, the notations and formulation of the model are presented.

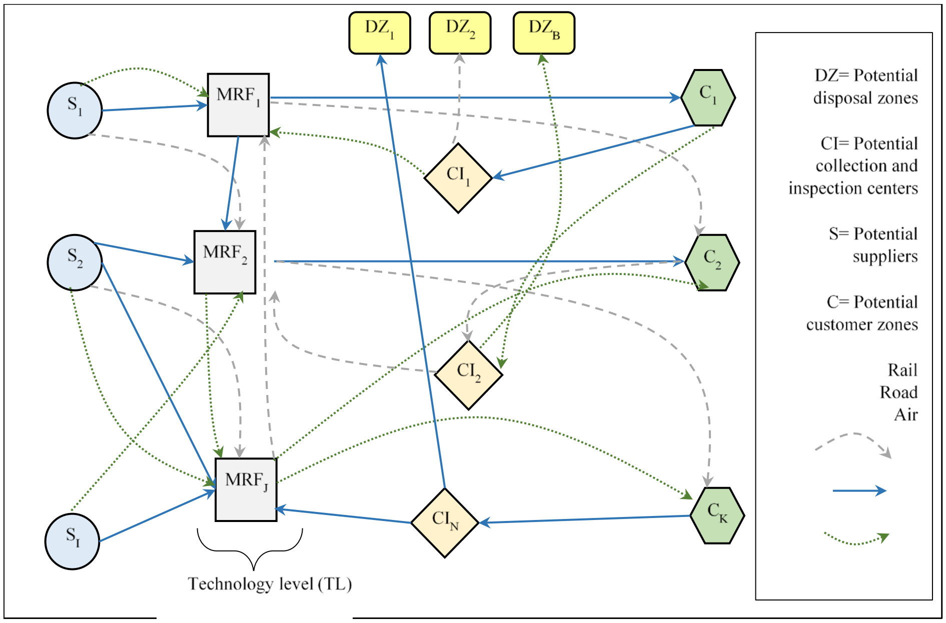

Figure 1. Closed-loop network with considering transportation modes

Assumption:

1. suppliers, MRFs, CIs, C, and DZs have a limited capacity and the number of them is predetermined
2. The model is single-period and the locations of customer zones are fixed and predicted and all demands should be met.
3. The amount of Co2 emission from each technology level and transportation mode is uncertain.
4. The quality of manufactured products from returned products and other manufactured products are the same
5. According to incomplete and/or the unavailability of the required data and their reliance on qualitative opinions of experts, critical parameters (such as customer demand, supply, opening cost based on the technology level, transportation mode costs, and Co2 emission) are Fuzzy.
6. Transmission capacity is limited for all three transportation modes.

In order to overcome uncertainties embedded in demand and supply, the following strategies are defined:

i. Multi-source model instead of a single source for supply is available and the returned products are considered as one of the sources of supplies.
ii. Transportation at each echelon is considered, and a switch between MRFs to compensate uncertainty in the demand and supply of products is intended.
iii. Triangular fuzzy numbers and possibility programming are considered to deal with the uncertainty of the model.

The indices, parameters and variables used to formulate the concerned supply chain network design problem are described below.

Indices

i Index of suppliers (*i=1,...,I*)
j Index of MRF (*j=1,…,J*)
k Index of customer zones (*k=1,…,K*)
m Index of transportation modes (*m=1,…,M*)
b Index of Disposal zones (*b=1,…,B*)
n Index of collection and inspection zones (*n=1,…,N*)
l Index of environmental technology level of each MRF (*l=1,…,L*)
p Index of number of products *(p=1, …, P)*

Decision variables

$$y_j = \begin{cases} 1 \ \ if\ MRF\ j\ is\ opened \\ 0 \end{cases}$$

x_{ijmp} Quantity of stock shipped from supplier *i* to MRF *j* for manufacturing product p with transportation mode *m* (units)

x_{jkmp} Quantity of product *p* shipped from MRF *j* to customer zone *k* with transportation mode *m* (units)
$x_{jj'mp}$ Quantity of product *p* shipped from MRF *j* to MRF j' with transportation mode *m* (units)
x_{njmp} Quantity of product *p* shipped from CI *n* to MRF *j* with transportation mode *m* (units)
x_{knmp} Quantity of product *p* shipped from customer zone *k* to CI *n* with transportation mode *m* (units)
x_{nbmp} Quantity of product *p* shipped from CI *n* to DZ *b* with transportation mode *m* (units)
z_{jl} The environment protection in MRF *j* under environmental technology level *l*
$zz_{jl} = \begin{cases} 1 & if\ MRF\ j\ opened\ under\ environmental\ level\ l \\ 0 & \end{cases}$
$\tilde{g}_{jl}$ Linguistic variable for environmental investment cost on environmental technology level *l* in MRF *j*
$\widetilde{w}_{jl}$ Linguistic variable for Co_2 emission of environmental technology level *l* in MRF *j*
LPN A very large positive number

$\widetilde{w}_{jl}$ and $\tilde{g}_{jl}$ are linguistic variables for the evaluation of environmental levels of facilities. $\tilde{g}_{jl}$ is a linguistic variable that denotes the environmental investment in MRF j at environmental technology level l and MIC denotes fix maximum investment cost on environmental levels of facilities. $\widetilde{w}_{jl}$ is a linguistic variable that denotes the Co_2 emission in MRF j for handling product and MCO2E denotes fix the maximum quantity of Co_2 emission. Seven levels have been defined for $\widetilde{w}_{jl}$ and $\tilde{g}_{jl}$.

The first objective function is minimizing the expected total cost. Equation (1) estimates the overall expected cost of the supply chain network considering the opening of the MRF and transshipment between the MRFs. The first expression of equation (1) is indicative of opening the MRF. In the second expression, the environmental investment level of the MRF is considered, having been explained for seven different technology levels using fuzzy variables; the value will be variable based on the technology selection. The third, fourth, fifth, and sixth sections show the total transportation cost between the centers. In the fourth expression, the cost savings resulting from the production of recovered products are modeled. The fifth section in addition to estimating the transportation costs of disposal specifies the disposal cost in DZ. The seventh section determines the cost of transshipment between the MRFs. In the last section of the equation, the production costs in MRFs are considered.

$$\begin{aligned} Z-TC: min \sum_{j=1}^{J} \tilde{f}_j y_j &+ \sum_{j=1}^{J}\sum_{l=1}^{L} MIC.\tilde{g}_{jl}.zz_{jl} + \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{m=1}^{M} \widetilde{Cn}_{knm} x_{knmp} \\ &+ \sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{m=1}^{M} (\widetilde{Cn}_{njm} - Cs_{jp}) x_{njmp} + \sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{b=1}^{B}\sum_{m=1}^{M} (\widetilde{Cn}_{nbm} + Cd_{bp}) x_{nbmp} \\ &+ \sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} \widetilde{Cn}_{ijm} x_{ijmp} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} \widetilde{Cn}_{jkm} x_{jkmp} \\ &+ \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{j'=1, j'\neq j}^{J}\sum_{m=1}^{M} \widetilde{Cp}_{jj'm} x_{jj'mp} + \sum_{p=1}^{P}\sum_{j=1}^{J} Co_{jp} \sum_{k=1}^{K}\sum_{m=1}^{M} x_{jkmp} \end{aligned} \tag{1}$$

The second objective function is Minimization of carbon dioxide emission.

The second objective function Minimization of carbon dioxide emission in the network and the negative impacts of technology selection. Environmental pollution mitigation in the supply chain can be defined as decreasing greenhouse gas emissions. In this model the decrease of carbon dioxide emission has been calculated for different types of transportation modes as well as reducing such emissions in production activities of MRFs; in general, the minimization of pollution in long-term and mid-term planning has been dealt with. In this study, the calculation is made using the product of pollution resulting from the transportation mode types multiplied by the products shipped by each mode. Also, the pollution of MRFs has been calculated based on the environmental technology level. Transshipment of materials among the MRFs indirectly affects the above-mentioned function. Obviously, the lower value of this function leads to a cleaner and greener closed-loop supply chain.

$$\begin{aligned} Z-CO2E: min \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} \tilde{e}_{ijm} x_{ijmp} &+ \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} \tilde{e}_{jkm} x_{jkmp} + \sum_{j=1}^{J}\sum_{j'=1, j'\neq j}^{J}\sum_{m=1}^{M} \tilde{e}_{jj'm}\, x_{jj'mp} \\ &+ \sum_{k=1}^{K}\sum_{n=1}^{N}\sum_{m=1}^{M} \tilde{e}_{knm} x_{knmp} \\ &+ \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{m=1}^{M} \tilde{e}_{njm} x_{njmp} + \sum_{n=1}^{N}\sum_{b=1}^{B}\sum_{m=1}^{M} \tilde{e}_{nbm} x_{nbmp} + \sum_{j=1}^{J}\sum_{l=1}^{L} MCO2E.\widetilde{w}_{jl}.zz_{jl} \end{aligned} \tag{2}$$

equation (2) represents the green objective. There are seven expressions in the equation. The first six expressions indicate the co2 emission between the supply chain echelon considering different transportation mode types. The last expression will be used for estimating the pollution resulting from the production technology level in MRFs.

Constraints

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{m=1}^{M} x_{ijmp} + \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{m=1}^{M} x_{njmp} - \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} x_{jkmp} = 0 \quad \forall p \tag{3}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} x_{jkmp} + \sum_{j=1}^{J}\sum_{j'=1,j\prime\neq j}^{J}\sum_{m=1}^{M} (x_{jj'mp} - x_{j'jmp}) \cong \sum_{k=1}^{K} \widetilde{D}_{kp} \quad \forall p \tag{4}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M} x_{ijmp} \cong \tilde{S}_{ip} \qquad \forall j,p \tag{5}$$

$$\sum_{k=1}^{K}\sum_{m=1}^{M} x_{knmp} \cong \tilde{v}_{kp} \qquad \forall n,p \tag{6}$$

$$\sum_{n=1}^{N}\sum_{m=1}^{M} x_{nbmp} \cong q.\tilde{v}_{kp} \qquad \forall b,p \tag{7}$$

$$r_j \sum_{i=1}^{I}\sum_{m=1}^{M} x_{ijmp} + r_j \sum_{n=1}^{N}\sum_{m=1}^{M} x_{njmp} \cong \tilde{u}_j y_j \qquad \forall j,p \tag{8}$$

$$\sum_{p=1}^{P} x_{ijmp} \le \widetilde{Ca}_{ijm} \qquad \forall i,j,m \tag{9}$$

$$\sum_{p=1}^{P} x_{jkmp} \le \widetilde{Ca}_{jkm} \qquad \forall j,k,m \tag{10}$$

$$\sum_{p=1}^{P} x_{jj'mp} \le \widetilde{Ca}_{jj'm} \qquad \forall j,m \tag{11}$$

$$\sum_{p=1}^{P} x_{knmp} \le \widetilde{Ca}_{knm} \qquad \forall k,n,m \tag{12}$$

$$\sum_{p=1}^{P} x_{njmp} \le \widetilde{Ca}_{njm} \qquad \forall j,n,m \tag{13}$$

$$\sum_{p=1}^{P} x_{nbmp} \le \widetilde{Ca}_{nbm} \qquad \forall n,b,m \tag{14}$$

$$\sum_{l=1}^{L} zz_{jl} \le LPN.y_j \qquad \forall j \tag{15}$$

$$\sum_{l=1}^{L} zz_{jl} = 1 \qquad \forall j \tag{16}$$

Constraint 3 shows that the input flow to the MRF is affected through the supplier (forward flow) and CI (return flow) and is equal to the product flow from the manufacturing and remanufacturing centers to the customer zones. Constraint 4 guarantees the balance of the inventory in MRF with indefinite demand predicted by the model. This type of relocation (at a specific level) occurs when one of the centers is faced with over-capacity and the other with an under-capacity state in the second part of constraint 4. Constraint 5 applies the capacity constraint of the suppliers. Constraint 6 ensures that the total sum of the returning flows is approximately equal to the predicted amount of returned items. Constraint 7 describes the approximate equality of the total sum of flows to the disposal center with the disposal rate of the products. Constraint 8 indicates the limited capacity in each MRF, the total sum of material flow from the suppliers (forward flow), and the total sum of flow from the CIs (return flow). Constraints 9, 10, 11, 12, 13, and 14 respectively are equal to the constraint of transportation from the supplier to MRFs, from MRFs to the customer zones, from the MRFs to each other (lateral transshipment in the same level of supply chain), from the customer zones to the CIs (return flow) and from the CIs to the DZs (return flow).

Constraint 15 ensures the selection of the technology level in case of the establishment of MRFs. In constraint 16 it is ensured that only one of the technology levels is selected for any MRF. In this article, the method of Jimenez et al (2007) was used to check the uncertainty of the parameters of the problem, and the method of Mula et al (2006) was used to check the uncertainty in the limits. Also, the TH method has been used to solve the multi-objective model. In the following, more details about each of the methods and the final model will be provided Torabi and Hassini (2008).

4. Data Collection

In this section two examples in different sizes are presented (see Table 1). First the sensitivity analysis of the models is presented and afterwards the solution of the example using GAMs software and the findings are evaluated and analyzed in terms of different dimensions. In the introduced example several MRFs have been considered which relate to different suppliers with uncertainty in supplying stocks. In the meantime the returning flow from the collection and inspection centers also will play role as a supplier in the production process. Although we face with high uncertainty in return flow supply chain, this flow however can overcome the uncertainty from other suppliers and thereby add to the stability of supply chain network. Also the understudy model considers seven models of technology levels for establishment of manufacturing and remanufacturing facility. It is notably both of the examples are single product and single period model.

Table 1. Feature of solved example

Example	Technology level	Transportation mode	DZ	CI	Customer zones	MRF	supplier
1	7	3	1	2	3	3	3
2	7	3	2	6	18	15	12

The other parameters' values required for solving the understudy problem have been randomly produced. In this regard, three prominent parameters including the most likely (A^m), the most pessimistic (A^p), and the mostoptimistic (A^o) parameters) are estimated for each imprecise parameter. First, the most likely (C^m) value of each parameter is provided randomly (using the uniform distributions specified in Table 2) and the corresponding crisp value is equal to the most likely value for all parameters when the proposed crisp model is applied. To estimate the most pessimistic (C^p) and most optimistic (C^o) parameters, the most like parameter has been multiplied by 0.8 and 1.2, respectively (Pishvaee and Torabi 2010).

Table 2. The sources of random generation of the most likely values.

Parameters	Corresponding random distribution
$\tilde{\boldsymbol{f}}_{\boldsymbol{j}}$	~uniform(40000, 100000)
$\widetilde{\boldsymbol{D}}_{\boldsymbol{k}}$	~uniform(900, 1500)
$\tilde{\boldsymbol{v}}_{\boldsymbol{k}}$	~uniform(300 ,1000)
$\tilde{\boldsymbol{S}}_{\boldsymbol{i}}$	~uniform(600 ,1500)
$\tilde{\boldsymbol{u}}_{\boldsymbol{j}}$	~uniform(500 ,1500)
$\widetilde{\boldsymbol{Cn}}_{\boldsymbol{ijm}}$	~uniform(50, 250)
$\widetilde{\boldsymbol{Cn}}_{\boldsymbol{jkm}}$	~ uniform(50, 250)
$\widetilde{\boldsymbol{Cp}}_{\boldsymbol{jj'm}}$	~uniform(40 , 100)
$\widetilde{\boldsymbol{Cn}}_{\boldsymbol{knm}}$	~ uniform(50, 250)
$\widetilde{\boldsymbol{Cn}}_{\boldsymbol{njm}}$	~ uniform(50, 250)
$\widetilde{\boldsymbol{Cn}}_{\boldsymbol{nbm}}$	~ uniform(50, 250)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{ijm}}$	~uniform(250 ,800)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{jkm}}$	~uniform(200 ,600)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{jj'm}}$	~uniform(200 ,600)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{njm}}$	~uniform(200 ,600)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{knm}}$	~uniform(200 ,600)
$\widetilde{\boldsymbol{Ca}}_{\boldsymbol{nbm}}$	~uniform(200 ,600)
$\tilde{\boldsymbol{e}}_{\boldsymbol{ijm}}$	~uniform(150 ,250)

Parameters	Corresponding random distribution
$\tilde{e}_{jkm}$	~uniform(150 ,250)
e_{knm}	~uniform(150 ,250)
e_{njm}	~uniform(150 ,250)
e_{nbm}	~uniform(150 ,250)
$\tilde{e}_{jj'm}$	~uniform(50 ,150)

5. Results and Discussion

According to methodology presented in section 3, here first the uncertainty of the parameters and constraints of numerical example is determined, and then the two-objective model of the problem is solved. In the end the results obtained from resolving the numerical example is evaluated and the analysis of sensitivity on some of the parameters such as α and γ relating to the parameters certainty level and the model limitations is given. The level of α affects the uncertain parameters' values and the rate of γ is influential on the vague and uncertain constraints of the model.
Next through changing the significance level of the objectives based on different values of the comparison of the optimum answers has been performed. Nevertheless, the effect of transshipment of the materials between MRFs on the green supply chain network design has been assessed. The main questions of examples are as follows:

- Which MRFs centers should be established?
- Which environmental levels are assigned to the manufacturing and remanufacturing centers (if any)?
- Which transportation mode between different nodes (MRF, CI, DZ, suppliers, and customer zones) should be selected?
- The lateral transshipment between which MRFs are developed?

To solve the model and answer to the main questions, first the value of ψ in TH method is assumed as equal to 0.5 for the solution of two-objectives problem; also identical objective weights of θ_η are assumed for both objectives as equal to 0.5. Table 3 represents the numerical results of sensitivity analysis of the α value and the related effect on the problem objectives. The numerical sensitivity analysis results of γ value on the problem objectives assuming the constancy of α is presented in Table 4.

Table 3. Numerical results of sensitivity analysis of the α value example 1

γ-level	α-level	θ_η (θ_1, θ_2)	ψ -value	Z_1	Z_2	$\mu(Z_1)$	$\mu(Z_2)$
0.5	0.5	(0.5,0.5)	0.5	1917593	1333530	0.797	0.792
	0.6			1917593	1332660	0.797	0.794
	0.7			1921437	1330340	0.794	0.797
	0.8			1928531	1324199	0.792	0.804
	0.9			1928531	1324199	0.792	0.804
	1			1948730	1321282	0.774	0.807

Table 4. Results of sensitivity analysis of γ-level for example1

γ-level	α-level	θ_η (θ_1, θ_2)	ψ -value	Z_1	Z_2	$\mu(Z_1)$	$\mu(Z_2)$
0.1	0.5	(0.5,0.5)	0.5	1902579	1321280	0.808	0.807
0.2				1907583	1324199	0.804	0.804
0.3-0.4				1912588	1327269	0.800	0.800
0.5-0.9				1917593	1330340	0.796	0.797

Results of both graphs indicate that both objectives' changes are not so much dependent on the α and γ values, showing the accuracy of the selected method for solution of the two-objective model. Also as expected, by the increase in the γ value shown in (Table 4), i.e. increasing the uncertainty of constraints, both objectives distance from the optimum solution.
Also selecting greater values for ψ means more focus for obtaining a higher value for “lower bound for satisfaction degree of objective” (σ_0) and consequently the final obtained answer will be a more balanced solution. On the

contrary, selecting a smaller value for ψ is indicative of more focus for obtaining an answer with high satisfaction degree for some goals of the problem without giving special attention to satisfaction level of other objectives. The final solution therefore shall be a more non- balanced answer. It can be seen from the above table that as per lower values of ψ no balance shall exist between satisfactions of the objectives. But by the increase in the above parameter value from 0.4 onwards the satisfaction of both objectives is effected with higher balance.
In order to show the importance of transshipment between MRFs (lateral transfer) after the arrival of stock in each center by suppliers, we solve the second example under two different scenarios. Table 4 shows the fulfillment of both objectives under two scenarios.

- First scenario: solving the example by considering the lateral transhipment of prosucts between manufacturing and re-manufacturing centers.
- Second scenario: solving the example without considering lateral transhipment of prosucts between manufacturing and re-manufacturing centers.

Best solution of objective 1: (Scenario 2) Z1=7336952, (Scenario 1) Z_1=7158752, R1 = (scenario 1) Z_1 - (Scenario 2) Z_1 =178200;
Best solution of objective 2: (Scenario 2) Z_2=5186702, (Scenario 1) Z_2=5084204, R1 = (scenario 1) Z_2 - (Scenario 2) Z_2 =102500.

It can be observed that by selecting identical technology levels for the MRFs in above scenarios, the value of both objectives in the first scenario (considering transshipment between the manufacturing and remanufacturing centers) is lower than the second scenario and because the problem in both objectives is of optimization type, the second scenario gives better answer both in terms of the expected cost minimization and greenness and minimization of carbon dioxide emission. Also due to the identical level of technology in both scenarios it can be argued that the lateral transshipment between MRFs in addition to encountering with uncertainty in supply and demand, reduces the pollution level resulting from the transportation in the network.

6. Conclusion

The issue of supply chain network design has been the focus of researchers in different ways. The various relationships between the main components of the supply chain network, the way of transportation between the components, the closed loop and attention to various social and environmental requirements are among the factors that have been mentioned in recent articles in this field. The problem of 5 echelons of the supply chain including suppliers, MRFs, customer zones, CIs, and disposal zones in which it is possible to return the product is the main issue studied in this article. This routine model, which has been previously discussed in various articles, can be examined from several aspects. First, what will be the transportation procedure between and within the echelons in terms of cost and pollution. Second, what is the level of technology chosen in MRFs in terms of cost and pollution. Thirdly, what pattern does the returned product from the customer return to the cycle? And fourth, whether there is a possibility of intra-echelon transfer. On the other hand, the uncertainty hidden in the parameters and limitations of the problem and the multi-targeting of the problem are other main aspects of the articles related to this field. This paper studies the integration of transshipment in supply chain network design with multiple suppliers, multiple manufacturing and remanufacturing facilities, multiple customer zones, multiple collection and inspection centers and disposal centers, under an imprecise/fuzzy environment. As an aspect that was observed to be lacking in the literature, in this paper lateral transshipment between MRFs is considered. Transshipment policies might improve customer satisfaction and responsiveness to customer demand in closed-loop supply chain. In order to mitigating transportation capacity uncertainty, we applied multi-mode transportation system. Multi-mode transportation system leads to reduce total costs and Co2 emission as well. The proposed supply chain network design includes environmental consideration in both transportation process and environmental technology level of MRF. Subjective parameter based on linguistic variables is another important aspect for interacting decision making based on cost and environmental variables. In this paper a multi objective mixed integer programming model is proposed for minimizing total cost and environmental influence. Since most of the parameters in such a problem have imprecise nature, a possibilistic programming is applied to dealing with epistemic parameters i.e., cost, and environmental influence. To solve the proposed MOPMILP model, an interactive fuzzy solution approach is proposed by combining the Jimenez and TH methods. The proposed framework provides the efficient solutions based on decision maker preferences to incorporate their expertise as well as their historical knowledge regarding the system under study into the model in order to obtain an optimal production network. By defining the variable of quantity of product shipped from MRF j to MRF j′, the amount of lateral transshipment was considered in the model. Based on the obtained results, by adding this variable and its equivalent constraints, compared to the case where there is no lateral transportation, in average the amount of the total cost of the model and the amount of reduction of CO2 emissions have decreased by 2.5% and 2%, respectively. This average value is obtained based on different levels of coefficients and the degree of weighting to the objectives in the TH method (which leads to the production of balanced and unbalanced responses) and the alpha coefficient in dephasing the model. The most important advantage of our article is the definition of different levels of environmental technology in the creation of MRF and the existence of literal transshipment. In this paper, some assumptions were considered in the original model, which can be developed in future papers. For example, differentiating the quality and demand for recovered products from the quality and demand for normal products can be an interesting aspect for future studies. Also, considering different land, rail and air routes for transportation and adding the issue of routing as well as location of MRFs are other aspects that can be added to the model.

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