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A green closed-loop supply chain for production and distribution of perishable products

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Abstract *– Nowadays, the importance of supply chain management (SCM) includes timely and efficient decisions at strategic, tactical, and operational levels while addressing economic and environmental aspects. Meanwhile, designing an optimal supply chain to produce and distribute perishable items is of specific significance because of its prominent role in the human food pyramid. Delivery time of these products plays an important role which can directly affect customer satisfaction and is known as one of the main challenges. We try to develop a novel bi-objective model to configure a closed-loop supply chain network (SCN) for such products considering economic and environmental issues. Furthermore, according to the bi-objectiveness of our suggested model, the ε-constraint approach (EC) is employed to validate the model in small-scale instances. The obtained results showed that the model has an appropriate efficiency in solving the problems. Eventually, managerial insights are presented using the sensitivity analysis method for key parameters of the problem. It is demonstrated that the objective functions are so sensitive to the demand parameter where 20% increase and 10% decrease in this parameter lead to the most significant changes in the 1st and 2nd objective functions, respectively.*

Keywords*– Closed-loop supply chain network, Customer satisfaction, Perishable products, ε-constraint approach, Sensitivity analysis.*

I. INTRODUCTION

The design of supply chains and related transportation and logistics systems is an important issue for all segments of society due to its effects on the main factors of the country's economy, such as production, price, employment, and cost of living metric (Haddadsisakht and Ryan, 2018). In the past, each production center tried to increase its market share by paying attention to the number of products produced, but in today's competitive environment, it is obvious that production centers and companies seek to create strategic and operational decisions to optimize and manage their logistic systems. Therefore, to gain more advantage in the market, they should look for solutions by which they can reduce costs and increase customer satisfaction continuously and simultaneously. Customer satisfaction increases if

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products and goods reach customers within a certain time. Especially in the fields of perishable products, research has shown that shipping costs are a great part of the cost of the products. One of the vital operational decisions related to these challenges is the use of a multi-level system for the distribution of goods, which results in a large decrease in costs and improves service quality. In addition to the economic aspects, the use of this type of distribution system leads to reduced traffic, environmental pollution, and noise in the city centers because the vehicles of the last level are smaller and provide more satisfaction to the citizens (Özceylan et al., 2014; Khorshidvand et al., 2021).

Perishable products are items that may be damaged or spoiled over time by changes in temperature, pressure, humidity, or any environmental conditions, such as food, dairy, vegetables, meat, medicine, etc. (Yavari and Geraeli, 2019). The perishable supply chain has always been one of the most significant and attractive subjects in supply chain management (SCM) at different times. The challenge for companies in managing perishable food supply chains is that the value of the product is highly dependent on the environment over time. Shipping time, temperature, pressure, and humidity are the key elements in transporting perishable items. Carrying such materials, it is necessary to observe the requirements in which the mentioned variables can be controlled. Any changes in the mentioned elements can affect the quality of the shipped products. Failure to comply with the required standards at any point in the supply chain of perishable products can cause irreparable damage to the customer's products and make them unusable. Therefore, choosing the shipping method is highly important. So, the distribution of perishable products throughout the supply chain with the highest quality is one of the most significant competitive measures in the field of perishable products, and corporations must take this concept into consideration while designing the optimal supply chain (Diabat et al., 2019).

This study intends to offer a novel mathematical model for a green closed-loop supply chain network (SCN) for perishable products, which tries to minimize the total cost and environmental pollution at the same time. To validate the offered model, the bi-objective model is first transformed into a single-objective model by the ε-constraint approach and then is solved by designing numerical instances in the CPLEX solver.

The structure of the remaining sections is given as follows. Section 2 reviews the literature of this work in the form of previous research. The proposed problem and the proposed modeling are given in Section 3. Section 4 describes the ε-constraint technique. The validation of the suggested model and the computational results are given in Section 5, and finally, in Section 6, the conclusions and future suggestions are described.

II. PREVIOUS STUDIES

According to the literature, there are limited studies that have been performed in the field of the perishable SCM are reviewed as well as literature related to forward, reverse, and closed-loop SCNs.

Kannan et al. (2010) offered a multi-period multi-product multi-level mixed-integer linear programming model (MILP) model for battery recycling and implemented a case study. The decisions made in this model were for preparation, production, distribution, return, and disposal of materials. Pishvaee et al. (2010) offered a multi-objective MILP model that aims to maximizing network responsiveness and minimizing total cost in a closed-loop SCN. To treat the suggested problem, a genetic algorithm (GA) was applied. Zarandi et al. (2011) introduced a multi-objective closed-loop SCN design problem and solved it by a fuzzy goal programming (GP) method. In this network, the five-level of forwarding flow contains suppliers, manufacturers, warehouses, retailers, and customers, and the three-level of reverse flow consists of customers, collection centers, and recovery centers. In their model, it is assumed that warehouses are separate from factories, and different levels of capacity and potential locations are taken into account for factories and warehouses, which the model determines their optimal location and capacity. Likewise, the flows between these facilities should be determined by the model. Aras et al. (2011) suggested a nonlinear model for finding the location of collection centers for the used product in a simple reverse logistics network. A noteworthy point in this paper is the ability of the model to determine the purchase price of used products from its owners to maximize profits. To tackle the problem, they employed a heuristic approach based on the Tabu search (TS) algorithm. Mahmoudzadeh et al. (2013)

offered a model in which the optimal location of collection facilities for expired products is determined. Three quality levels are considered for product collection. On the other hand, different qualities have been proposed for recycled raw materials in recycling centers, which leads to the comprehensive performance of the model. Ramos et al. (2014) offered a multi-objective model for designing a reverse logistics network, in which the first and second objectives correspond to costs and environmental materials, and the 3rd objective function is related to social responsibility. Tactical and strategic decisions were optimized concurrently in their proposed model.

Ozceylan et al. (2014) modeled an integrated closed-loop SCN and optimized the disassembly line balance. This paper considered strategic and tactical decisions simultaneously within a closed-loop SCN. The main goal was to reduce the total cost as much as possible, including transportation, purchase, renovation, and dismantling station operations. Amin and Zhang (2014) provided a multi-objective mathematical model including several commodities, factories, recycling technologies, demand markets, and collection centers. This problem is to minimize the costs of the given SCN, in addition to minimizing the waste rate and operation time in collection centers. Soleimani and Kannan (2015) designed a large-scale multi-period, multi-level, multi-product closed-loop SCN. They combined GA and particle swarm optimization (PSO) algorithms to improve the efficacy of the GA by considering the positive aspects of PSO. Rezapour et al. (2015) proposed a closed-loop SCN in a price-dependent and competitive demand market. A bi-level model was proposed in which reverses strategic network decisions were made at the higher level, and the tactical and operational planning of the closed-loop SCN was done at the lower level. There is competition between two supply chains to supply new products to similar markets and between a new SCN to supply a new or remanufactured product. Keshavarz et al. (2017) studied an uncertain multi-period multi-product reverse logistics SCN. The objectives of their problem were to minimize the total cost and maximize the total green points from the purchased raw materials. Safaei et al. (2017) designed a robust mathematical model to configure the cardboard closed-loop SCN. Their goal was to maximize total profits by taking into account operating costs, transportation costs, purchasing costs, and inventory maintenance costs. The computational results obtained from their research were able to provide effective solutions for the supply chain.

Haddad Sisakht and Rayan (2018) developed a closed-loop SCN by considering different modes of transportation considering stochastic demand, and uncertain carbon tax rates. The objective function was to minimize the total SCN cost at three levels. Kavyanfar et al. (2018) suggested a stochastic multi-product multi-level mathematical model design the supply chain of small and medium industries in the clustering industry. Their suggested model tried to minimize the total cost, which was solved by benders decomposition. Moreover, they presented a real case study with sensitivity analysis to evaluate its efficiency. Dai et al. (2018) suggested a nonlinear model with fuzzy constraints to solve the location-routing problem using GAs and harmonic search algorithm (HAS) in a three-level SCN of perishable products. Their objective was to reduce the total cost of the SCN as much as possible. They employed LINDO software to evaluate their proposed algorithms, and it was found that the proposed algorithms have a high ability to solve problems in a suitable operating time. Mardan and Kamranrad (2020) offered a MILP model to address a bi-objective closed-loop SCN configuration problem. They examined a real case study problem using the weighted GP approach. A location-routing-inventory problem (LRRIP) was recently addressed within a closed-loop SCN by Navazi et al. (2021). Non-dominated sorting genetic algorithm II (NSGA-II) was employed to tackle the problem using test problems. Finally, Table I provides a summary of dominant and relevant research conducted in recent years.

In this study, a novel MILP model is provided to design a green closed-loop SCN to manage the distribution of perishable items. Finally, after reviewing the literature, it is concluded that the research gap includes the following:

1. Configuring a green closed-loop SCN considers assumptions such as different production technology and different modes of transportation specific to perishable products.
2. Developing a novel bi-objective MILP model in order to concurrently minimize the total cost and total amount of emissions,
3. Taking into account special equipment and service at specific time windows to address the perishability of the products,

4. Considering recycling centers as one of the key actors to address sustainable development,
5. Making integrate optimal decisions for inventory management, location, and allocation of facilities and transportation planning,
6. Sensitivity analysis of key parameters to examine the behavior of objective functions and to develop managerial insights.

Table I. A summary of previous research in closed-loop supply chain

Reference	Year	Levels of network								Features	Objectives				Solution methods
		Suppliers	Production	Collection	Recovery	Distribution	Recycling	Repair	Disposal	Perishability	Responsiveness	Environmental	Social	Economic	
Pishvaee & Torabi	2010		◘		◘	◘	◘	◘			◘			◘	ε-constraint
Wang et al.	2011	◘	◘			◘						◘		◘	ε-constraint
Pishvaee et al.	2012		◘			◘						◘		◘	CPLEX
Chaabane et al.	2012	◘	◘			◘	◘					◘		◘	LINGO
Tseng & Hung	2014	◘	◘			◘								◘	Exact method
Pishvaee et al.	2014		◘	◘			◘		◘			◘	◘	◘	LINGO
Govindan et al.	2014		◘			◘						◘		◘	Benders decomposition
Devika et al.	2014	◘	◘	◘		◘	◘	◘	◘			◘	◘	◘	Lingo
Azadeh et al.	2015	◘	◘	◘				◘				◘		◘	ε-constraint
Wu et al.	2017	◘	◘				◘				◘			◘	NSGA-II
Keshavarz Ghorabaee et al.	2017	◘	◘	◘	◘							◘		◘	GAMS
Cheraghalipour et al.	2018	◘	◘	◘	◘							◘		◘	NSGA-II
Kayvanfar et al.	2018	◘	◘	◘	◘				◘			◘	◘	◘	Benders decomposition
Dai et al.	2018		◘	◘						◘				◘	LINGO
Yavari & Geraeli	2019	◘	◘	◘		◘				◘		◘		◘	Heuristics
Mardan & Kamranrad	2020	◘	◘	◘	◘	◘			◘		◘			◘	Weighted goal programming
Khorshidvand et al.	2021	◘	◘	◘	◘	◘			◘			◘		◘	weighted sum method and Lagrangian relaxation and subgradient algorithm
Nasr et al.	2021	◘	◘	◘		◘			◘			◘	◘	◘	Fuzzy goal programming approach
Navazi et al.	2021		◘						◘	◘	◘	◘		◘	NSGA-II
Current work	2021	◘	◘	◘		◘	◘		◘	◘		◘		◘	ε-constraint

III. PROBLEM DESCRIPTION

In designing the supply chain of perishable products, customer satisfaction increases if products and goods reach customers within a certain period. Research has shown that a significant portion of the cost of products is related to shipping costs. In this regard, one of the vital operational decisions is the use of a multi-level system for the distribution of products, which leads to a large reduction in costs and improves service quality. In addition to the economic aspects, the use of this type of distribution system leads to a reduction in traffic, environmental pollution, and noise in city centers because the final level vehicles are smaller and provide more satisfaction to the citizen.

In this problem, a seven-level closed-loop SCN including suppliers, production facilities, distribution centers (DCs), and customers to build up the forward logistics, and collection, disposal, and recovery facilities in the reverse logistics is considered. Figure 1 shows the proposed seven-level SCN.

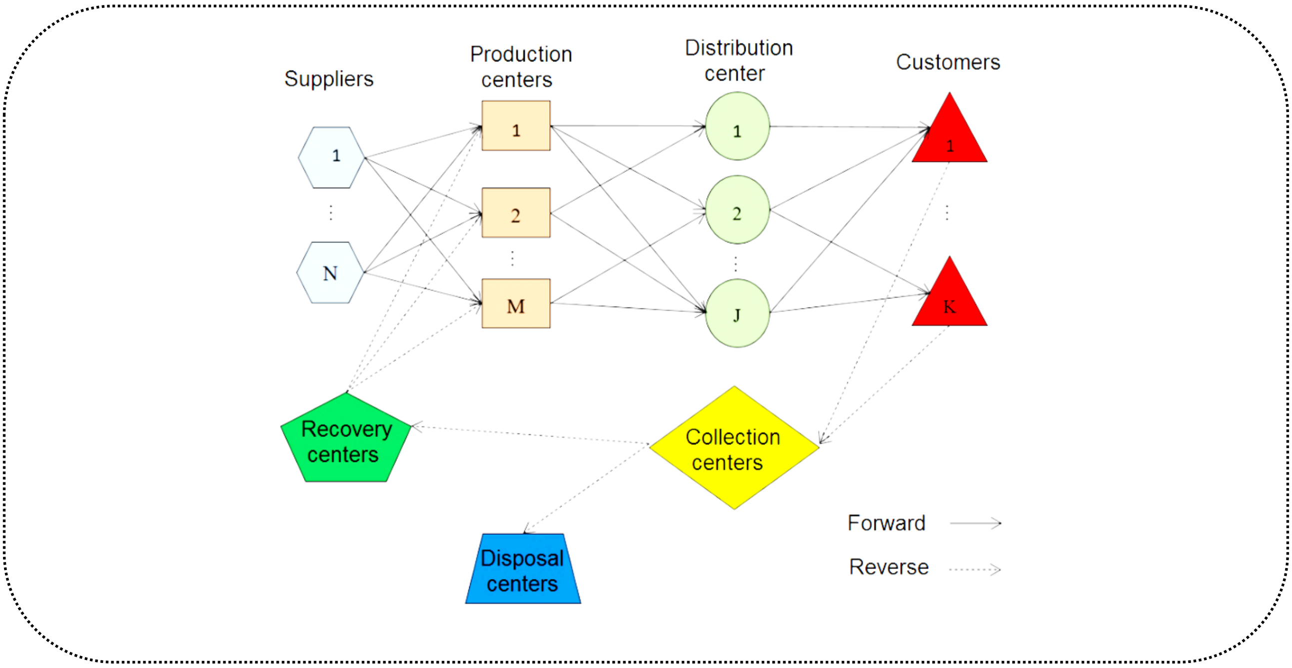

Figure 1. The proposed SCN.

According to the proposed network, the problem aims to

i. identify the optimal locations of facilities at five levels of production, distribution, collection, disposal, and recovery,
ii. calculate the number of products in production centers, the number of raw materials supplied from suppliers,
iii. determine the level of inventory in DCs, the number of perishable items transported from production facilities to DCs, from DCs to customers, the number of products given back from customers to collection facilities, and the number of products sent from collection facilities to disposal facilities and recovery facilities,

So that the total cost of the SCN and the total amount of pollutant emissions to be minimized.

Furthermore, at the production level, various production technologies along with various modes of transport between levels are considered. Also, an important feature of this supply chain is the timely supply and distribution of raw materials and products due to their perishable nature. In the following, the main assumptions of the model are presented.

1. The proposed SCN includes seven levels: 1) suppliers 2) manufacturer 3) distributor 4) customer 5) collection centers 6) disposal centers, and 7) recovery centers.
2. Determining the optimal location is done in 5 levels of manufacturer, distributor, collection, recovery, and disposal centers.
3. Several modes of transportation systems are considered in the SCN.
4. Several levels of production technology are considered.
5. The capacity of various facilities and centers is limited.
6. Costs of facility location, transportation, inventory shortage, and maintenance are fixed.
7. The problem is planned for one period.
8. In each planning period, a certain time is considered for the delivery of raw materials from suppliers to production centers and delivery of products from DCs to customers.
9. Inventory shortage can occur DCs.
10. Several types of raw materials and several types of final products are considered
11. The volume of pollutant emissions depends on the amount of load, and the distance traveled between different levels.
12. Each raw material is used in the production of the final product with a specific consumption coefficient.

Now, the notations of the proposed mathematical are given in the following:

Sets and indices

s	Suppliers ($s \in S$),
p	Production facilities ($p \in P$),
d	DCs ($d \in D$),
c	Customers ($c \in C$),
m	Collection facilities ($m \in M$),
q	Disposal facilities ($q \in Q$),
o	Recovery facilities ($o \in O$),
t	Time periods ($t \in T$),
r	Final items ($r \in R$),
a	Set of raw materials supplied from suppliers ($a \in A$),
e	Set of transportation systems from suppliers to production centers ($e \in E$),
f	Set of transportation systems from production centers to DCs ($f \in F$),
g	Set of transportation systems from DCs to the customers ($g \in G$),

h	Set of transportation systems from customers to the collection facilities, from collection facilities to recovery and disposal facilities and from there to the production center ($h \in H$),
w	Set of production technology ($w \in W$).

Parameters

DE_{crt}	Demand of customer *c* for final item *r* at period *t*,
DA_{art}	Quantity of raw material type *a* needed to provide one unit of final item *r* at period *t*,
RA_{ar}	Consumption coefficient of raw material type *a* for producing one unit of final item *r*,
OA_{aro}	Recovery coefficient of final item *r* to raw material type *a* in the recovery center *o*,
CAS_{sa}	Capacity of supplier *s* to supply raw material type *a* in each period,
CAP_{prw}	Capacity of production facility *p* for final item *r* with technology *w* in each period,
CAD_{dr}	Capacity of DC *d* for final item *r* in each period,
CAM_{mr}	Capacity of collection facility *m* for final item *r* in each period,
CAQ_{qr}	Capacity of disposal facility *q* for final item *r* in each period,
CAO_{or}	Capacity of recovery facility *o* for final item *r* in each period,
ESP_{spate}	Cost of transporting raw material *a* from the supplier *s* to the producer *p* with transportation system *e* in the period *t*,
GSP_{spae}	Amount of CO_2 emission in transporting a unit of raw material a from the supplier s to the producer *p* with transportation system *e*,
TSP_{spae}	Preparation and transportation time of raw material *a* from supplier *s* to production facility *p* with transportation system *e*,
EPD_{pdrtf}	Cost of transporting the final item *r* from manufacturer *p* to distributor *d* with transportation system *f* in period *t*,
GPD_{pdrf}	Cost of transporting final item *r* from manufacturer *p* to distributor *d* with transportation system *f* at period *t*,
EDC_{dcrtg}	Cost of transporting final item *r* from distributor *d* to customer *c* with transportation system *g* at period *t*,

GDC_{dcrg} Amount of CO_2 emission in transporting a unit of final item *r* from distributor *d* to customer *c* with transportation system *g*,

TDC_{dcrg} Preparation and transportation time of final item *r* from distributor *d* to customer *c* with transportation system *g* in each period,

ECM_{cmrth} Cost of transporting the final item *r* from customer *c* to collection facility *m* with transportation system *h* at period *t*,

GCM_{cmrh} Amount of CO_2 emission in transporting a unit of final item *r* from customer *c* to collection facility *m* with transportation system *h*,

EMQ_{mqrth} Cost of transporting the final item *r* from collection facility *m* to disposal facility *q* with transportation system *h* at period *t*,

GMQ_{mqrh} Amount of CO_2 emission in transporting a unit of final item *r* from collection facility *m* to disposal facility *q* with transportation system *h*,

EMO_{morth} Cost of transporting the final item *r* from collection facility *m* to recovery facility *o* with transportation system *h* at period *t*,

GMO_{morh} Amount of CO_2 emission in transporting a unit of final item *r* from collection facility *m* to recovery facility *o* with transportation system *h*,

EOP_{oprth} Cost of transporting the returned processed final item *r* to recover in recovery facility *o* and production facility *p* with transportation system *h* at period *t*,

GOP_{oprh} Amount of CO_2 emission in transporting a unit of returned processed final item *r* to recover in recovery facility *o* and production facility *p* with transportation system *h* at period *t*,

UE_e Capacity of transportation system *e*,

UF_f Capacity of transportation system *f*,

UG_g Capacity of transportation system *g*,

DS_{sp} Distance between supply center s and producer *p*,

DB_{pd} Distance between producer *p* and distributor *d*,

DC_{dc} Distance between distributor *d* and customer *c*,

DD_{cm}	Distance between customer *c* and collection facility *m*,
DM_{mq}	Distance between collection center *m* and disposal facility *q*,
DF_{mo}	Distance between collection center *m* and recovery facility *o*,
DG_{op}	Distance between recovery facility *o* and producer *p*,
α_{rc}	Flow rate of returned final item *r* from customer *c* in each period,
β_r	Flow rate of disposable final item *r* which is transferable from collection facilities to disposal facilities,
CP_{prtw}	Production cost of final item *r* at period *t* by producer *p* with technology *w*,
CD_{drt}	Processing cost of final item *r* in DC *d* at period *t*,
CM_{mrt}	Processing cost of final item *r* in collection facility *m* at period *t*,
CQ_{qrt}	Processing cost of final item *r* in disposal facility *q* at period *t*,
CO_{ort}	Processing cost of final item *r* in recovery facility *o* at period *t*,
FP_{ptw}	Fixed cost of establishing production facility *p* at period *t* with production technology *w*,
FD_{dt}	Fixed cost of establishing DC *d* at period *t*,
FM_{mt}	Fixed cost of establishing collection center *m* at period *t*,
FQ_{qt}	Fixed cost of establishing disposal center *q* at period *t*,
FO_{ot}	Fixed cost of establishing recovery center *o* at period *t*,

HD_{drt} Unit inventory cost of final item *r* in DC *d* at period *t*,

BD_{drt} Unit shortage cost of final item *r* in DC *d* at period *t*,

(LP_{at}, UP_{at}) Time window for supplying raw materials type *a* at period *t* to manufacturers,

(LC_{crt}, UC_{crt}) Time window for delivering final item *r* at period *t* to customer *c*,

MM A very large number.

Variables

XP_{prtw} Quantity of final item *r* produced by producer *p* at period *t* by the production technology *w*,

XA_{spate} Quantity of raw material type *a* transported from supply center *s* to production facility *p* at period *t* with the transportation system *e*,

XB_{pdrtf} Quantity of final item *r* transported from production facility *p* to DC *d* at period *t* and with transportation system *f*,

XC_{dcrtg} Quantity of final item *r* transported from DC *d* to customer *c* at period *t* and with transportation system *g*,

XD_{cmrth} Quantity of final item *r* returned from customer *c* to collection facility *m* at period *t* with transportation system *h*,

XE_{mqrth} Quantity of final item *r* transported from collection facility *m* to disposal facility *q* at period *t* and with transportation system *h*,

XF_{morth} Quantity of final item *r* transported from collection facility *m* to recovery facility *o* at period *t* and with transportation system *h*,

XG_{oparth} Quantity of recovered raw material *a* from final item *r* which is shipped from recovery facility *o* to production facility *p* at period *t* with transportation system *h*,

AA_{spate} Binary variable showing whether raw material type *a* transported from supply center *s* to production center *p* at period *t* and with transportation system *e* or not,

BB_{dcrtg} Binary variable showing whether final item *r* transported from DC *d* to customer *c* at period *t* and with transportation system *g* or not,

YA_{pwt}	Binary variable showing whether production center *p* opens with production technology *w* at period *t* or not,
YB_{dt}	Binary variable showing whether DC *p* opens at period *t* or not,
YC_{mt}	Binary variable showing whether collection center *m* opens at period *t* or not,
YD_{qt}	Binary variable showing whether disposal center *q* opens at period *t* or not,
YE_{ot}	Binary variable showing whether recovery center *o* opens at period *t* or not,
IN_{drt}	Inventory of final item *r* in DC *d* at the end of period *t*,
BO_{drt}:	Shortage of final item *r* in DC *d* at the end of period *t*.

A. Proposed mathematical model

Now, the 1st objective function is to minimize the total SCN cost.

$$\begin{aligned} Min\ Z_1 = & \sum_s \sum_p \sum_a \sum_t \sum_e DS_{sp} ESP_{spate} XA_{spate} \\ & + \sum_p \sum_d \sum_r \sum_t \sum_f DB_{pd} EPD_{pdrtf} XB_{pdrtf} \\ & + \sum_d \sum_c \sum_r \sum_t \sum_g DC_{dc} EDC_{dcrtg} XC_{dcrtg} \\ & + \sum_m \sum_h \sum_c \sum_r \sum_t DD_{cm} ECM_{cmrth}\, XD_{cmrth} \\ & + \sum_m \sum_q \sum_r \sum_h \sum_t DE_{mq}\, EMQ_{mqrth} XE_{mqrth} \\ & + \sum_m \sum_o \sum_t \sum_r \sum_h DF_{mo}\, EMO_{morth} XF_{morth} \\ & + \sum_o \sum_p \sum_a \sum_r \sum_t \sum_h DG_{op}\, EOP_{oprth}\, XG_{oparth} \end{aligned} \quad \text{(a)}$$

$$+\sum_{w}\sum_{p}\sum_{t} FP_{ptw}YA_{pwt} + \sum_{d}\sum_{t} FD_{dt}YB_{dt} + \sum_{m}\sum_{t} FM_{mt}YC_{mt} + \sum_{q}\sum_{t} FQ_{qt}\, YD_{qt} + \sum_{o}\sum_{t} FO_{ot}YE_{ot} \tag{b}$$

$$+\sum_{d}\sum_{r}\sum_{t} HD_{drt}\, IN_{drt} + \sum_{d}\sum_{r}\sum_{t} BD_{drt}\, BO_{drt} \tag{c}$$

$$+\sum_{w}\sum_{p}\sum_{r}\sum_{t} CP_{prtw}\, XP_{prtw} + \sum_{p}\sum_{d}\sum_{r}\sum_{t}\sum_{f} CD_{drt}\, XB_{pdrtf} + \sum_{c}\sum_{r}\sum_{m}\sum_{t}\sum_{h} CM_{mrt}\, XD_{cmrth} + \sum_{h}\sum_{q}\sum_{m}\sum_{r}\sum_{t} CQ_{qrt}\, XE_{mqrth} + \sum_{h}\sum_{o}\sum_{m}\sum_{r}\sum_{t} CO_{ort}\, XF_{morth} \tag{d}$$

The first objective function consists of four parts. The first part covers transportation costs at each stage of the forward and reverse logistics. The first part also includes seven terms: the total cost of transportation between suppliers and producers, producers and distributors, distributors and customers, customers and collection facilities, collection and disposal facilities, collection and recovery facilities, and eventually between recovery facilities and producers. The second part includes the location cost of all facilities at different levels in the supply chain. This part of the objective function consists of 5 terms: the total cost of locating manufacturers, distributors, collection centers, disposal centers, and recovery centers. In the third part, inventory and shortage costs of the DCs are computed, respectively. Finally, in the fourth part, production costs, operating costs in DCs, collection and disposal, and recovery centers are determined.

$$\begin{aligned}
Min\ Z_2 = & \sum_{s}\sum_{p}\sum_{a}\sum_{t}\sum_{e} DA_{sp} GSP_{spae} XA_{spate} \\
& + \sum_{p}\sum_{d}\sum_{r}\sum_{t}\sum_{f} DB_{pd} GPD_{pdrf} XB_{pdrtf} \\
& + \sum_{d}\sum_{c}\sum_{r}\sum_{t}\sum_{g} DC_{dc} GDC_{dcrg} XC_{dcrtg} \\
& + \sum_{m}\sum_{r}\sum_{c}\sum_{t}\sum_{h} DD_{cm} GCM_{cmrh} XD_{cmrth} \\
& + \sum_{m}\sum_{q}\sum_{r}\sum_{t}\sum_{h} DM_{mq} GMQ_{mqrh}\, XE_{mqrth} \\
& + \sum_{m}\sum_{o}\sum_{h}\sum_{r}\sum_{t} DF_{mo}\, GMO_{morh} XF_{morth} \\
& + \sum_{t}\sum_{p}\sum_{a}\sum_{o}\sum_{r}\sum_{h} DG_{op} GOP_{oprh}\, XG_{oparth}
\end{aligned}$$

The 2nd objective function represents the minimization of the total amount of emissions among various levels of the SCN, including seven terms: the total amount of pollution emissions between suppliers and producers, producers and DCs, DCs and customers, customers and collection facilities, collection facilities and disposal facilities, collection facilities and recovery facilities, and eventually between recovery facilities and producers.

Constraints

$$XP_{prtw} \le CAP_{prw}.YA_{pwt} \qquad \forall p,w,t,r \tag{1}$$

Constraint (1) indicates the capacity limitation of each production center according to the level of technology in each period.

$$\sum_{w} YA_{pwt} \le 1 \qquad \forall p,t \tag{2}$$

Constraint (2) indicates that a level of technology must be chosen to build a production center.

$$\sum_{p}\sum_{e} XA_{spate} \le CAS_{sa} \qquad \forall s,a,t \tag{3}$$

Constraint (3) shows the capacity limitation of suppliers for supplying raw materials in each period.

$$\sum_{p}\sum_{f} XB_{pdrtf} \le CAD_{dr}.YB_{dt} \qquad \forall d,r,t \tag{4}$$

Constraint (4) indicates the capacity limitation of DCs for distributing the products to the customers.

$$\sum_{c}\sum_{h} XD_{cmrth} \leq CAM_{mr}.YC_{mt} \qquad \forall m,r,t \tag{5}$$

Constraint (5) represents the capacity limitation of collection facilities to collect returned products from the customer.

$$\sum_{m}\sum_{h} XE_{mqrth} \leq CAQ_{qr}.YD_{qt} \qquad \forall q,r,t \tag{6}$$

Constraint (6) indicates the capacity limitation of disposal centers for the processing and disposal of products sent from collection centers.

$$\sum_{m}\sum_{h} XF_{morth} \leq CAO_{or}.YE_{ot} \qquad \forall o,r,t \tag{7}$$

Constraint (7) indicates the capacity limitation of recovery centers to process and recover products sent from collection centers.

$$IN_{drt-1} + \sum_{g}\sum_{c} XC_{dcrtg} + BO_{drt} - \sum_{c} DE_{crt} = IN_{drt} \qquad \forall d,r,t \tag{8}$$

Constraint (8) guarantees the balance of inventories in DCs in each time period.

$$\sum_{s}\sum_{p}\sum_{e} XA_{spate} + \sum_{o}\sum_{p}\sum_{h} XG_{oparth} \geq DA_{art} \qquad \forall a,r,t \tag{9}$$

Constraint (9) indicates the minimum volume of raw materials required to produce the final products in each period.

$$\sum_{a}\left(\sum_{o}\sum_{h} XG_{oparth} + \sum_{s}\sum_{e} XA_{spate}\right).RA_{ar} = \sum_{d}\sum_{f} XB_{pdrtf} \qquad \forall r,t,p \tag{10}$$

Constraint (10) shows the balance of the volume of input materials to production centers, which should be equal to the volume of final products sent from that production center to DCs in each period and according to the coefficient of consumption of raw materials.

$$\sum_{p}\sum_{f} XB_{pdrtf} = \sum_{c}\sum_{g} XC_{dcrtg} \qquad \forall d, r, t \tag{11}$$

Constraint (11) shows the balance of the volume of input materials to DCs, which should be equal to the volume of final products sent from that DC to the customers in each period.

$$\sum_{m}\sum_{h} XD_{cmrth} = \alpha_{rc}.\sum_{d}\sum_{g} XC_{dcrtg} \qquad \forall r, c, t \tag{12}$$

Constraint (12) indicates the balance of the volume of input materials to collection centers, which should be equal to the volume of returned products (percentage of products received by the customer) by customers in each period.

$$\sum_{q}\sum_{h} XE_{mqrth} = \beta_{r}.\sum_{c}\sum_{h} XD_{cmrth} \qquad \forall r, t, m \tag{13}$$

Constraint (13) indicates the balance of the volume of input materials to disposal centers, which should be equal to the volume of sent products (percentage of the products of the collection center) by collection centers in each period.

$$\sum_{o}\sum_{h} XF_{morth} = (1-\beta_{r}).\sum_{c}\sum_{h} XD_{cmrth} \qquad \forall r, t, m \tag{14}$$

Constraint (14) indicates the balance of the volume of input materials to recovery centers, which should be equal to the volume of sent products (percentage of the products of the collection center) by collection centers in each period.

$$\sum_{p}\sum_{h} XG_{oparth} = OA_{aro}.\sum_{m}\sum_{h} XF_{morth} \qquad \forall a, r, o, t \tag{15}$$

Constraint (15) indicates the balance of the volume of input materials to recovery centers, which should be equal to the certain volume of recovered products (percentage of the products of the recovery center) by recovery centers in each period.

$$\sum_{s}\sum_{p}\sum_{a} XA_{spate} \le UE_{e} \qquad \forall e, t \tag{16}$$

Constraint (16) expresses the capacity limitation of the transport system *e* in each time period.

$$\sum_{d}\sum_{p}\sum_{r} XB_{pdrtf} \leq UF_f \qquad \forall f,t \tag{17}$$

Constraint (17) expresses the capacity limitation of the transport system *f* in each time period.

$$\sum_{d}\sum_{c}\sum_{r} XC_{dcrtg} \leq UG_g \qquad \forall g,t \tag{18}$$

Constraint (18) expresses the capacity limitation of the transport system *g* in each time period.

$$XA_{spate} \leq MM.\,AA_{spate} \qquad \forall s,p,a,t,e \tag{19}$$

Constraint (19) determines the relationship between the allocations of production centers to suppliers with the volume of sent raw materials in each period.

$$XC_{dcrtg} \leq MM.\,BB_{dcrtg} \qquad \forall d,c,r,t,g \tag{20}$$

Constraint (20) determines the relation between the allocations of customers to DCs with the volume of sent products in each period.

$$LP_{at}.\sum_{w} YA_{pwt} \leq \sum_{s}\sum_{e} TSP_{spae}.\,AA_{spate} \leq UP_{at}.\sum_{w} YA_{pwt} \qquad \forall a,t,p \tag{21}$$

Constraint (21) indicates the time window for receiving raw materials by production centers in each time period.

$$LC_{crt} \leq \sum_{g}\sum_{d} TDC_{dcrg}\,.\,BB_{dcrtg} \leq UC_{crt} \qquad \forall r,t \tag{22}$$

Constraint (22) indicates the time window for receiving products by DCs in each time period.

$$\sum_{d}\sum_{f} XB_{pdrtf} \leq \sum_{w} XP_{prtw} \qquad \forall r,t,p \tag{23}$$

Constraint (23) indicates that the volume of the product sent by production centers to DCs should not surpass its production volume in each period of each product.

$$YA_{pwt}, YB_{dt}, YC_{mt}, YD_{qt}, YE_{ot}, AA_{spate}, BB_{dcrtg} \in \{0,1\};$$

$$XP_{prtw}, XA_{spate}, XB_{pdrtf}, XC_{dcrtg}, XD_{cmrth}, XE_{mqrth}, XF_{morth}, XG_{opath} \geq 0;$$

$$IN_{drt}, BO_{drt} \geq 0 \quad \forall p,w,t,m,q,o,s,a,r,e,f,g,h \tag{24}$$

Constraint (24) specifies the domain of the variables.

IV. ε-CONSTRAINT METHOD

The ε-constraint approach is one of the most famous techniques for coping with multi-objective optimization problems, which tackles these problems by shifting all the objective functions into the set of constraints while keeping just one of them (Mavrotas, 2009). Finally, by identifying the number of breakpoints, the Pareto front is generated. As one of the important superiorities of the ε-constraint approach, it is able to tackle the number of generated efficient solutions while other exact techniques, such as the weighted sum technique, cannot provide it. By considering the values chosen (ε_i) for sub-objective functions, the model is then solved.

For our model, the ε-constraint method is employed through Model (25).

$$Min\ f1(x) \tag{25}$$

$$x \in X$$

$$f2(x) \leq \varepsilon_2$$

$$\ldots$$

$$fn(x) \leq \varepsilon_n$$

The main steps in the ε-constraint approach are given in the following:

1) Considering one of the objectives as the main objective function,
2) Based on each objective function, the model is optimized. Then, the optimal values of objective functions are determined.
3) The variation between the two optimal values of the second objective function is divided into several pre-determined parts. A table of values $\varepsilon_2, \ldots, \varepsilon_n$ is then generated.
4) The problem is solved by the main objective function and $\varepsilon_2, \ldots, \varepsilon_n$,
5) Pareto solutions are provided.

V. EXPERIMENTAL RESULTS

Here, the computational results are given and discussed according to the evaluation of the suggested model's functionality and the proposed solution technique.

A. Validation of the proposed methodology

In order to do the validation of the suggested methodology, a numerical example is considered to be solved. The required information of the network is given in Table II.

Also, the other parameters of the problem are randomly produced with uniform distributions according to Table III. Most of these parameters are adapted from the relevant research works in the literature of perishable products distribution, such as Dai et al. (2018) and Yavari and Geraeli (2019).

Table II. The small-size instance for the SCN

Facility	*Number*
Suppliers	4
Production facilities	3
DCs	3
Customers	5
Collection facilities	2
Recovery facilities	2
Disposal facilities	2
Products	2
Raw materials	2
Time periods	4
Technology levels	2
Transportation systems	2

Table III. Value of parameters

Parameter	*Value*
DE_{crt}	U(55, 88)
DA_{art}	U(150, 350)
CAS_{sa}	U(1000, 2500)
CAP_{prw}	U(1500, 3000)
$CAD_{dr}, CAM_{mr}, CAQ_{qr}, CAO_{or}$	U(2500, 4000)
TSP_{spae}	U(0.4, 1.5)
TDC_{dcrg}	U(0.5, 2)

Continue Table III. Value of parameters

Parameter	***Value***
$ESP_{spate}, EOP_{oprth}, EDC_{dcrtg}, EPD_{pdrtf}, ECM_{cmrth}, EMQ_{mqrth}, EMO_{morth}$	U(4, 5)
$GCM_{cmrh}, GMQ_{mqrh}, GPD_{pdrf}, GSP_{spae}, GDC_{dcrg}, GOP_{oprh}, GMO_{morh}$	U(2.28,4.56)
$DS_{sp}, DB_{pd}, DC_{dc}, DD_{cm}, DM_{mq}, DF_{mo}, DG_{op}$	U(500, 1500)
$CP_{prtw}, CD_{drt}, CM_{mrt}, CQ_{qrt}, CO_{ort}$	U(50, 100)
$FP_{ptw}, FD_{dt}, FM_{mt}, FQ_{qt}, FO_{ot}$	U(10000, 20000)
UE_e	U(400,500)
UF_f, UG_g	U(500,650)
HD_{drt}	U(100, 200)
BD_{drt}	U(100, 150)
RA_{ar}	U(0.3, 0.7)
OA_{aro}	U(0.1, 0.4)
α_{rc}	U(0, 0.5)
β_r	U(0, 0.3)

The instance has been solved in GAMS/CPLEX solver using the ε-constraint approach in about 32 seconds in Table IV.

Table IV. Solution results.

Pareto Solution No.	***ε-constraint***	
	Obj 1	***Obj 2***
1	4769448.52	63835.32
2	4819596.50	61826.72
3	4897304.47	57407.70
4	5129590.31	52456.54
5	5233112.95	50038.57

According to Figure 2, the blue dots show the solutions obtained from the ε-constraint approach. As can be observed, the obtained solution has a high variability due to different costs and pollutants.

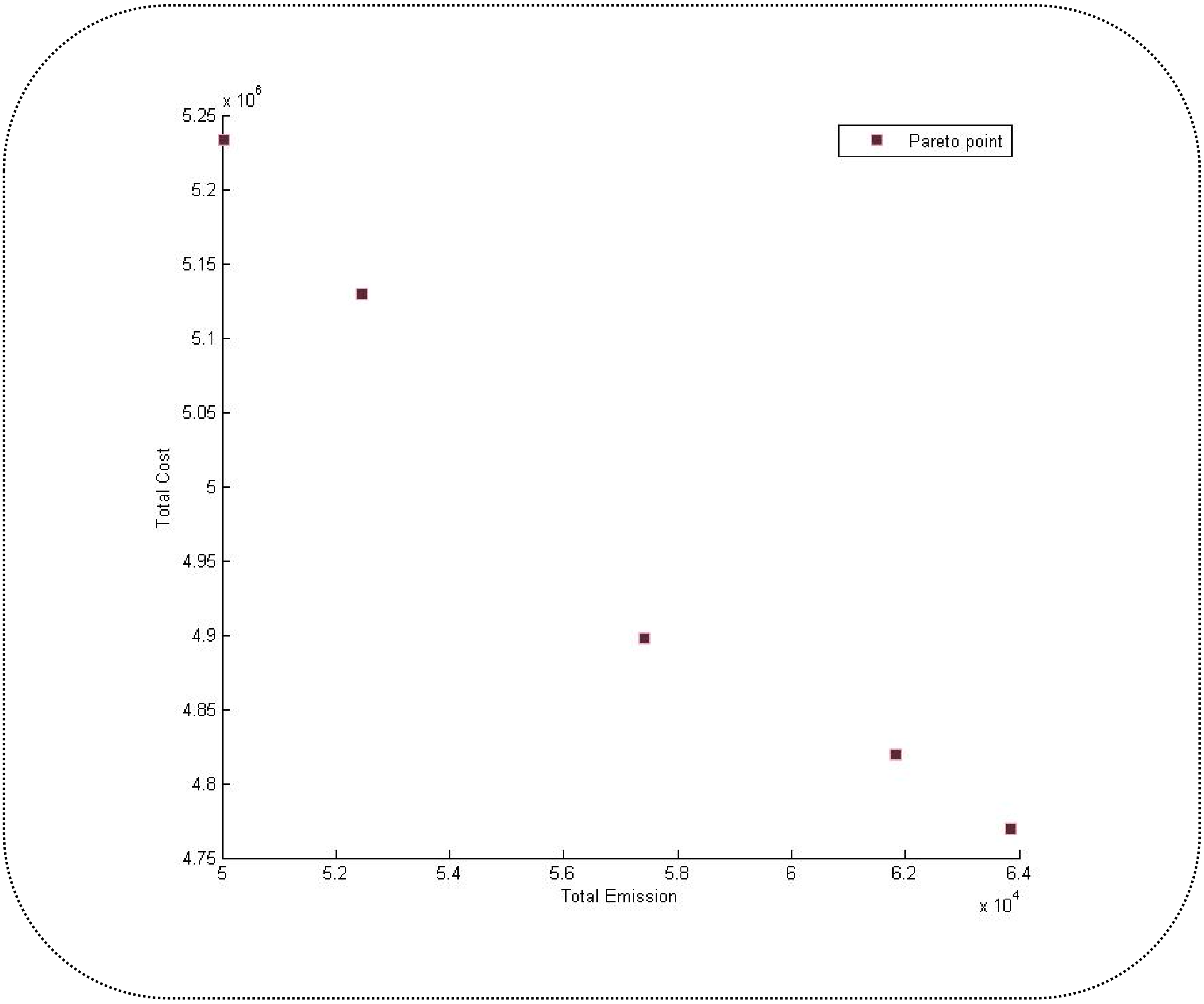

Figure 2. Pareto optimal solutions generated by the suggested method.

B. SENSITIVITY ANALYSIS

Here, sensitivity analysis of the important parameters affected on objective function is performed considering the 3rd Pareto point as the selected solution. Firstly, the rate of disposable product impact on each objective function is investigated separately. Its amount varies from -20 to +20 percent. Figure 3 shows the variation of the objective function according to the disposable product parameter.

As illustrated by Figure 3, increasing the amount of disposable product rate causes to raise the total cost while the emission amount has more negligible effect than the disposable rate variation.

The customer demand is also analyzed to investigate its effect on each objective function. To do this end, its amount is changed from -20% to 20%. Figure 4 depicts the trend of objective function according to demand variation.

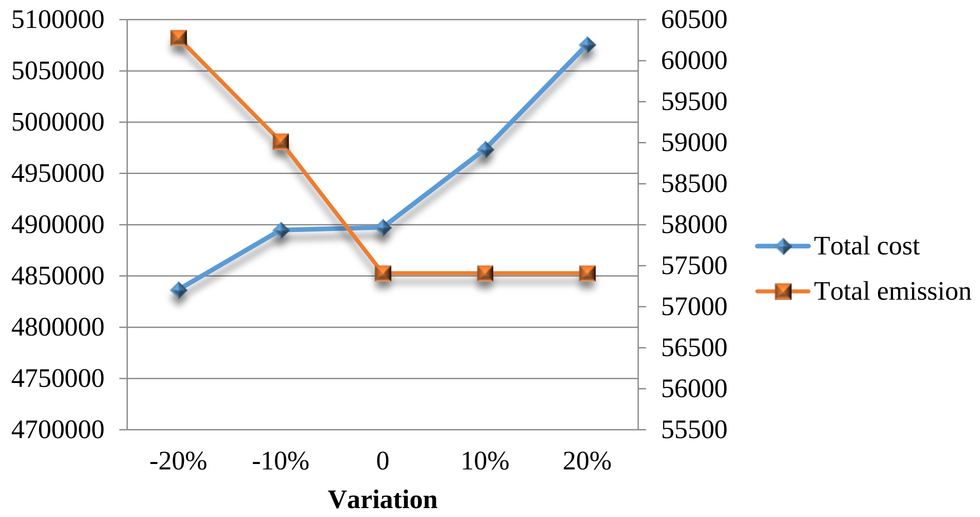

Figure 3. Effects of the disposable rate variations on the objective functions.

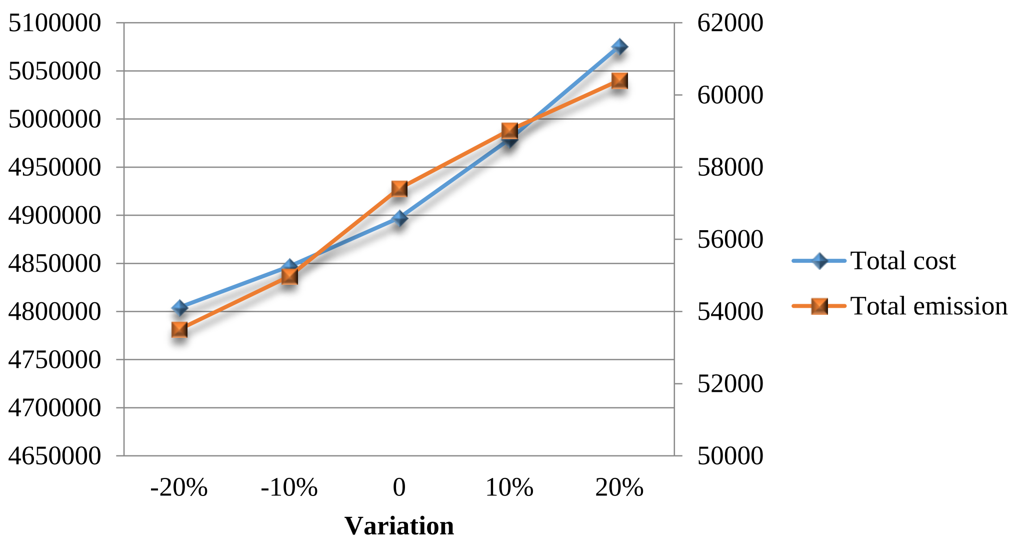

Figure 4. Effects of the demand variations on the objective functions.

As depicted in Figure 4, increasing the amount of demand causes to increase both the total cost and emission amount. Finally, the impact of recoverable product rate is discussed. Figure 5 shows the objective function variation trend according to recoverable rate changes.

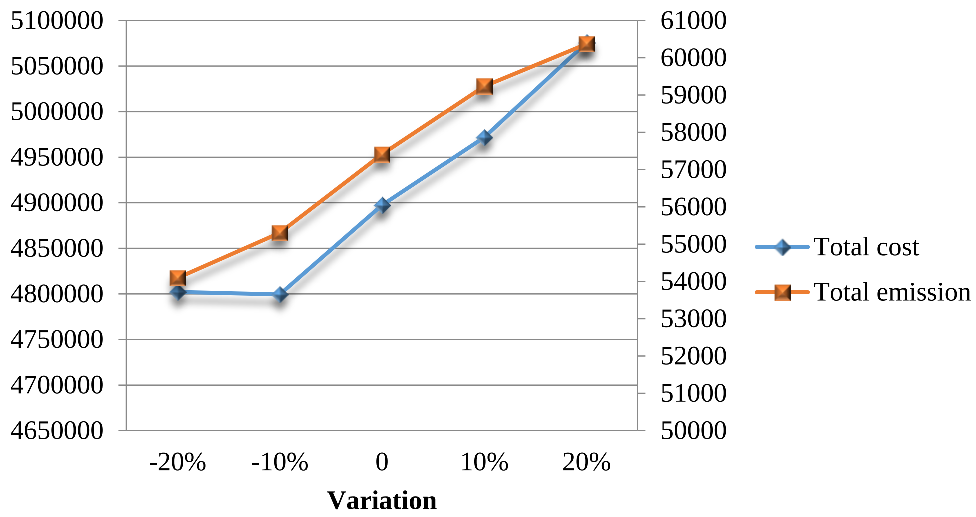

Figure 5. Effects of the recoverable rate variations on the objective functions.

As shown in Figure 5, the recoverable product rate variation does not have an equal effect on objective functions. Increasing this rate causes to increase the total cost, firstly, it will decrease while decreasing this rate does not significantly affect the costs. On the other hand, the emission amount is decreased by increasing the recoverable rate.

Finally, one of the most important cost-related parameters is considered to be analyzed; that is the unit shortage cost of products.

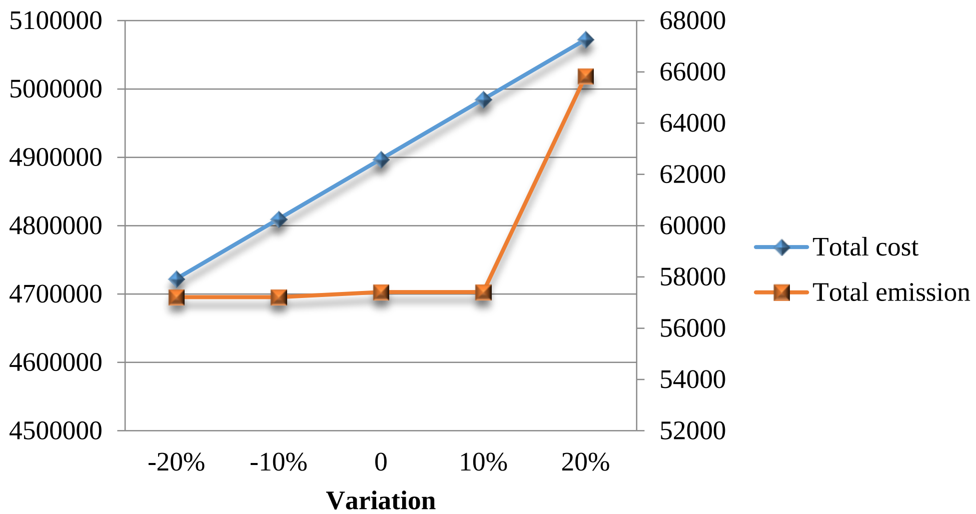

Figure 6. Effects of the unit shortage cost variations on the objective functions.

According to Figure 6, both objective functions are sensitive to the variations of unit shortage cost, where the 1st objective function is the most sensitive one. For the 20% increase in this parameter, both objective functions reflect the most variations.

To discuss and analyze the practical and managerial implications, it should be expressed that different parameters have various impacts on the objective functions. Since the objective functions are in conflict, it is critical that the decision-maker or management takes into account their importance levels and try to define the optimal policy through defining the number of resources. For example, both objectives reflect significant changes against demand variations which should be treated by allocating appropriate amounts of resources such as the capacity of facilities, transportation systems, etc. In some cases, the capacities need to be expanded by employing high-tech machinery, a skillful workforce, etc. On the other hand, the management always should consider the required resiliency against the uncertainty of parameters which results in a large amount of shortages.

However, as mentioned before, managers face some challenges, such as determining the number of products shipped among various centers and making locational and allocation decisions. The proposed model helps managers to decide about them with minimum possible costs and emissions. As a bi-objective model is developed, a Pareto solution frontier is obtained where managers select the suitable one based on their priorities.

VI. CONCLUSION

In this research, a green closed-loop SCN corresponding to the production and distribution of the perishable product was designed. The main contribution is the design of a backup decision system for planning the supply, production, and distribution of perishable products regarding major real-world assumptions such as different levels of technology and approved time windows for the distribution of products using vehicles with a suitable cooling system. The main objectives of the problem were to minimize the total cost of the network and the total amount of emissions at the chain levels. Furthermore, GAMS/CPLEX solver and ε-constraint method were employed as an exact method to solve the problem and prove the correctness and validation of the proposed model. For further study, the future suggestions are to introduce the concepts of reliability of facilities, route traffic, as well as the application of other meta-heuristic algorithms and comparing with the proposed research algorithm. Furthermore, the sustainable development concept can be studied in the problem as one of the recent significant subjects (Najafi et al., 2020; Tirkolaee et al., 2021a, 2021b; Khakbaz and Tirkolaee, 2021; Jahani et al., 2021).

REFERENCES

Amin, S. H., & Zhang, G. (2014). Closed-loop supply chain network configuration by a multi-objective mathematical model. International Journal of Business Performance and Supply Chain Modelling, 6(1), 1-15.

Aras, N., Aksen, D., & Tekin, M. T. (2011). Selective multi-depot vehicle routing problem with pricing. Transportation Research Part C: Emerging Technologies, 19(5), 866-884.

Azadeh, A., Raoofi, Z., & Zarrin, M. (2015). A multi-objective fuzzy linear programming model for optimization of natural gas supply chain through a greenhouse gas reduction approach. Journal of Natural Gas Science and Engineering, 26, 702-710.

Baghalian, A., Rezapour, S., & Farahani, R. Z. (2013). Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case. European Journal of Operational Research, 227(1), 199-215.

Behnamian, J., & Ghomi, S. F. (2014). Multi-objective fuzzy multiprocessor flowshop scheduling. Applied soft computing, 21, 139-148.

Bertsimas, D., & Sim, M. (2003). Robust discrete optimization and network flows. Mathematical programming, 98(1-3), 49-71.

Bertsimas, D., Pachamanova, D., & Sim, M. (2004). Robust linear optimization under general norms. Operations Research Letters, 32(6), 510-516.

Bérubé, J. F., Gendreau, M., & Potvin, J. Y. (2009). An exact ϵ-constraint method for bi-objective combinatorial optimization problems: Application to the Traveling Salesman Problem with Profits. European journal of operational research, 194(1), 39-50.

Boukherroub, T., Ruiz, A., Guinet, A., & Fondrevelle, J. (2015). An integrated approach for sustainable supply chain planning. Computers & Operations Research, 54, 180-194.

Chaabane, A., Ramudhin, A., & Paquet, M. (2012). Design of sustainable supply chains under the emission trading scheme. International Journal of Production Economics, 135(1), 37-49.

Chen, Z., & Andresen, S. (2014). A Multiobjective Optimization Model of Production-Sourcing for Sustainable Supply Chain with Consideration of Social, Environmental, and Economic Factors. Mathematical Problems in Engineering, 2014.

Cheraghalipour, A., Paydar, M. M., & Hajiaghaei-Keshteli, M. (2018). A bi-objective optimization for citrus closed-loop supply chain using Pareto-based algorithms. Applied Soft Computing, 69, 33-59 .

Dai, Z., Aqlan, F., Zheng, X., & Gao, K. (2018). A location-inventory supply chain network model using two heuristic algorithms for perishable products with fuzzy constraints. Computers & Industrial Engineering, 119, 338-352.

Deb, K., Pratap, A., Agarwal, S., & Meyarivan, T. A. M. T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. IEEE transactions on evolutionary computation, 6(2), 182-197.

Devika, K., Jafarian, A., & Nourbakhsh, V. (2014). Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques. European Journal of Operational Research, 235(3), 594-615.

Diabat, A., Jabbarzadeh, A., & Khosrojerdi, A. (2019). A perishable product supply chain network design problem with reliability and disruption considerations. International Journal of Production Economics, 212, 125-138.

Gold, S., Seuring, S., & Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: a literature review. Corporate social responsibility and environmental management, 17(4), 230-245.

Govindan, K., Jafarian, A., Khodaverdi, R., & Devika, K. (2014). Two-echelon multiple-vehicle location–routing problem with time windows for optimization of sustainable supply chain network of perishable food. International Journal of Production Economics, 152, 9-28.

Guillén-Gosálbez, G., & Grossmann, I. (2010). A global optimization strategy for the environmentally conscious design of chemical supply chains under uncertainty in the damage assessment model. Computers & Chemical Engineering, 34(1), 42-58.

Haddadsisakht, A., & Ryan, S. M. (2018). Closed-loop supply chain network design with multiple transportation systems under stochastic demand and uncertain carbon tax. International Journal of Production Economics, 195, 118-131.

Jahani, N., Sepehri, A., Vandchali, H. R., & Tirkolaee, E. B. (2021). Application of industry 4.0 in the procurement processes of supply chains: a systematic literature review. Sustainability, 13(14), 7520.

Keshavarz Ghorabaee, M., Amiri, M., Olfat, L., & Khatami Firouzabadi, S. A. (2017). Designing a multi-product multi-period supply chain network with reverse logistics and multiple objectives under uncertainty. Technological and Economic Development of Economy, 23(3), 520-548.

Kannan, G., Sasikumar, P., and Devika, K.B., (2010). A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling.Applied Mathematical Modeling, 34, 655– 670.

Kayvanfar, V., Husseini, S. M., Sajadieh, M. S., & Karimi, B. (2018). A multi-echelon multi-product stochastic model to supply chain of small-and-medium enterprises in industrial clusters. Computers & Industrial Engineering, 115, 69-79.

Khakbaz, A., & Babaee Tirkolaee, E. (2021). A sustainable hybrid manufacturing/remanufacturing system with two-way substitution and WEEE directive under different market conditions. Optimization, 1-24.

Khorshidvand, B., Soleimani, H., Sibdari, S., & Esfahani, M. M. S. (2021). A hybrid modeling approach for green and sustainable closed-loop supply chain considering price, advertisement and uncertain demands. Computers & Industrial Engineering, 157, 107326.

Lee, D.H., Dong, M., and Bian, W., (2010). The design of sustainable logistics network under uncertainty.International Journal of ProductionEconomics, 15 (3), 260–279.

Mahmoudzadeh, M., Mansour, S., & Karimi, B. (2013). To develop a third-party reverse logistics network for end-of-life vehicles in Iran. Resources, Conservation and Recycling, 78, 1-14.

Mardan, E., & Kamranrad, R. (2020). A Multi-objective Closed Loop Supply Chain Design: A Case Study in Iran. International Journal of Supply and Operations Management, 7(2), 119-128.

Najafi, N. V., Khamseh, A. A., & Mirzazadeh, A. (2020). An integrated sustainable and flexible supplier evaluation model under uncertainty by game theory and subjective/objective data: Iranian casting industry. Global Journal of Flexible Systems Management, 21(4), 309-322.

Nasr, A. K., Tavana, M., Alavi, B., & Mina, H. (2021). A novel fuzzy multi-objective circular supplier selection and order allocation model for sustainable closed-loop supply chains. Journal of Cleaner Production, 287, 124994.

Navazi, F., Sazvar, Z., & Tavakkoli-Moghaddam, R. (2021). A sustainable closed-loop location-routing-inventory problem for perishable products. Scientia Iranica. DOI: 10.24200/SCI.2021.55642.4353.

Özceylan, E., Paksoy, T., & Bektaş, T. (2014). Modeling and optimizing the integrated problem of closed-loop supply chain network design and disassembly line balancing. Transportation research part E: logistics and transportation review, 61, 142-164.

Pishvaee, M. S., Farahani, R. Z., & Dullaert, W. (2010). A memetic algorithm for bi-objective integrated forward/reverse logistics network design. Computers & operations research, 37(6), 1100-1112.

Pishvaee, M. S., & Torabi, S. A. (2010). A possibilistic programming approach for closed-loop supply chain network design under uncertainty. Fuzzy sets and systems, 161(20), 2668-2683.

Pishvaee, M. S., Rabbani, M., & Torabi, S. A. (2011). A robust optimization approach to closed-loop supply chain network design under uncertainty. Applied Mathematical Modelling, 35(2), 637-649.

Pishvaee, M. S., Torabi, S. A., & Razmi, J. (2012). Credibility-based fuzzy mathematical programming model for green logistics design under uncertainty. Computers & Industrial Engineering, 62(2), 624-632.

Pishvaee, M. S., Razmi, J., & Torabi, S. A. (2014). An accelerated Benders decomposition algorithm for sustainable supply chain network design under uncertainty: A case study of medical needle and syringe supply chain. Transportation Research Part E: Logistics and Transportation Review, 67, 14-38.

Ramos, T. R. P., Gomes, M. I., & Barbosa-Póvoa, A. P. (2014). Planning a sustainable reverse logistics system: Balancing costs with environmental and social concerns. Omega, 48, 60-74.

Ramezani, M., Bashiri, M., Tavakkoli-Moghaddam, R. (2013). “A new multi-objective stochastic model for a forward/reverse logistic network design with responsiveness and quality level”. Applied Mathematical Modelling, 37(1), 328-344.

Rezapour, S., Farahani, R. Z., Fahimnia, B., Govindan, K., & Mansouri, Y. (2015). Competitive closed-loop supply chain network design with price-dependent demands. Journal of Cleaner Production, 93, 251-272.

Sadeghi, J., & Niaki, S. T. A. (2015). Two parameter tuned multi-objective evolutionary algorithms for a bi-objective vendor managed inventory model with trapezoidal fuzzy demand. Applied Soft Computing, 30, 567-576.

Safaei, A. S., Roozbeh, A., & Paydar, M. M. (2017). A robust optimization model for the design of a cardboard closed-loop supply chain. Journal of Cleaner Production, 166, 1154-1168.

Soleimani, H., & Kannan, G. (2015). A hybrid particle swarm optimization and genetic algorithm for closed-loop supply chain network design in large-scale networks. Applied Mathematical Modelling, 39(14), 3990-4012.

Tirkolaee, E. B., Abbasian, P., & Weber, G. W. (2021a). Sustainable fuzzy multi-trip location-routing problem for medical waste management during the COVID-19 outbreak. Science of the Total Environment, 756, 143607.

Babaee Tirkolaee, E., & Aydın, N. S. (2021b). A sustainable medical waste collection and transportation model for pandemics. Waste Management & Research, 0734242X211000437.

Tseng, S. C., & Hung, S. W. (2014). A strategic decision-making model considering the social costs of carbon dioxide emissions for sustainable supply chain management. Journal of environmental management, 133, 315-322.

Wang, F., Lai, X., & Shi, N. (2011). A multi-objective optimization for green supply chain network design. Decision Support Systems, 51(2), 262-269.

Wu, Z., Kwong, C. K., Aydin, R., & Tang, J. (2017). A cooperative negotiation embedded NSGA-II for solving an integrated product family and supply chain design problem with remanufacturing consideration. Applied Soft Computing, 57, 19-34.

Yavari, M., & Geraeli, M. (2019). Heuristic method for robust optimization model for green closed-loop supply chain network design of perishable goods. Journal of Cleaner Production, 226, 282-305.

Yu, H., Solvang, W. D., & Chen, C. (2014). A green supply chain network design model for enhancing competitiveness and sustainability of companies in high north arctic regions. International Journal of Energy and Environment, 5(4), 403-418.

Zadeh, L.A., “Fuzzy sets”, Infection Control, Vol. 8, pp. 338-353, 1965.

Zarandi, M.H., Haddad-Sisakht, A., and Davari, S. (2011). Design of a closed-loop supply chain (CLSC) model using an interactive fuzzy goal programming.International Journal of Advanced Manufacturing Technology, 56, 809–821.

Zhang, Q., Shah, N., Wassick, J., Helling, R., & Van Egerschot, P. (2014). Sustainable supply chain optimisation: An industrial case study. Computers & Industrial Engineering, 74, 68-83.