Original Research

A Facility Location Problem in a Green Closed-Loop Supply Chain Network Design by Considering Defective Products

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Abstract

This paper proposes a bi-objective model for a green closed-loop supply chain network design. Four levels for forward and five levels for reverse flow were considered, including plants, distribution centers, online retailers, traditional retailers and customers for forward flow and customers, collecting centers, disposal centers, repair centers and plants for the reverse flow. The objectives are minimizing the GHG emission and maximizing profit by considering defective products and a second market for these products. Also, online retailers were considered alongside with traditional ones, since the Covid-19 pandemic has led to increase in the amount of online shopping. GAMS software and the Lpmetric technique were used to solve the model in the small and medium sizes. However, for the large size, we used Grasshopper Optimization Algorithm (GOA) as a meta-heuristic approach since solving the large size problem with GAMS is a complicated and time-consuming process. We provided Numerical and computational results to prove the efficiency and feasibility of the presented model. Finally, the managerial insights and future works were provided.

Keywords- CO2 emission; Defective product; Grasshopper Optimization Algorithm (GOA); Green Closed-loop supply chain; Mixed-integer programming

Introduction

In recent decades, the increase in demand, people's ability to buy products from other cities or even other countries, have had remarkable effects on industry and enticed firms to produce more. More production enables firms to better answer their customers' demands and gain more profit. However, on the other hand, it causes lots of environmental problems, such as greenhouse gas emission, scarcity of resources (Tumpa et al., 2019), and waste disposal (Zhu et al., 2007). Not only the process of production and distribution but also, in some cases the products themselves cause environmental pollution (Perpah et al., 2016). These issues, have given rise to Green Supply Chain (GSC) (Zhu et al, 2007). The focus of GSCs in every step is environmental safety to decrease production's and distribution's negative environmental impacts (Tumpa et al., 2019). It is proven that turning to GSCs provided firms with higher benefits (Srivastava, 2007) and helped them to improve their market share and strengthen their brand images (Min and Kim, 2012). Green supply chain management is an environmental approach to sourcing and production that considers sustainability in every supply chain stage (Tavana et al., 2021). Another approach to reducing pollution and waste and better saving resources is to dispose, recover, recycle, or resell used or defective products (De Giovanni and Zaccour, 2014). This is reachable by the combination of forward and reverse logistics in a supply chain which creates what is called Closed-Loop Supply Chain (CLSC). In other words, a CLSC is a system that focuses on the maximization of value creation over the product's life-cycle to enable the manufacturers to take advantage of the products in different situations (end-of-life, ruined, and so on) and save the environment (R Jr and Van, 2009; Dehghan-Bonari et al., 2021).

There are several steps in producing products to deliver them to customers, such as providing raw material, manufacturing the products in the plants, sending them to distribution centers, and then to customers. Supply Chain Network (SCN) uniforms these activities in two levels of production and distribution to gain the chains' goals more efficiently and increase the firms' competitive advantage (Fathollahi-Fard et al, 2018). Facility location problems manage a supply chain and simultaneously find the best location for establishing plants, distribution centers and retailers to design the best possible network and achieve the chain's goals as to seek the best SCN for the manger's purposes.

Those mentioned above motivated us to propose a bi-objective model for a facility location green CLSC network design problem to minimize environmental impacts of manufacturing and transportation and maximize profit. Many studies only focused on controlling the GHG emitted in the production process and proposed a particular cost to the GHG emission and considered it a part of the total cost. Nonetheless, this paper not only considered GHG emission in production but also included all the GHG emitted in distributing products from every node "a" to "b". Additionally, it proposes a separate objective function that focuses on minimizing the GHG emission. To answer the demands, this paper separates the retailers into two categories: online retailers and traditional retailers as lots of people have turned into online shopping due to the pandemic caused by the Coronavirus. The second objective function maximizes the profit, which will enable the managers to assess the effect of different prices on their profitability and choose the best price. Additionally, we considered defective products as a percent of a total produced products and a second market customers to buy those defective products with lower prices. This paper reviews the literature in Green Closed-Loop Supply Chain and then proposes a bi-objective mixed-integer linear programming model.

The model is solved in small and medium-size with GAMS. Then the small and medium size problems are again solved with meta-heuristic approach, Grasshopper Optimization Algorithm (GOA), to compare the results gained with GAMS and GOA and prove the applicability of GOA to be used for solving the large size problem. Finally, a conclusion is presented to show the model's results and its usage in real life.

The paper proceeds as follows, in section 2 we provided a thorough literature review. Section three includes a detailed explanation of the problem that is being addressed in this paper followed by section four which provides the reader with the mathematical model and all the related notations. In section five, we have explained our solution approaches to solve the previously mentioned mathematical model. In the same section, comparative analysis has also been provided to prove the applicability and validity of our proposed meta-heuristic algorithm in solving the model compared the exact method. Sensitivity analysis was done in section six in which various combination of parameters have been fed into model and the results were analyzed. In regard to section 7, namely discussion, we came up with insight full managerial suggestions based on our findings in section 6. Finally, section 8 wraps the whole paper up with a conclusion and recommended future approaches.

LITERATURE REVIEW

Initially introduced by Stollsteimer (1961) and Balinski (1965), the facility location problem (FLP), aims to determine the location of an undetermined number of facilities (each associated with a decision variable), with the goal of setup cost minimization (de Armas et al., 2017). Facility layout design (FLD) has a very important effect on the performance of a manufacturing system (Tohidi, 2015). The broad spectrum of FLP applications has put it under the spotlight in many studies in the context of supply chain management (SCM), healthcare management, and emergency logistics (Serrano et al., 2015). In this regard, Li et al. (2014) proposed an objective function to minimize total location, handling, and transportation costs in a multi-product facility location problem. Bieniek (2015) addressed a single-source capacitated facility location problem with random variables with discrete, continuous, or mixed distributions. A decision support framework was proposed by Anvari and Turkay (2017) in which the triple bottom line accounting of sustainability is taken into account. Shavarani et al. (2018) introduced a multilevel facility location problem to find the optimum number of required drones to cover all the demands in more recent years. Chauhan et al. (2019) developed a novel greedy and three-stage heuristics to maximize the coverage using an integer linear programming formulation. Ortega et al. (2020) considered a facility location problem from the experts' point of view in a transportation system that private vehicle users can transfer to public transport to complete their journey.

As mentioned in the introduction, firms are adopting reverse SC in addition to forward SC, forming what is known as a Closed-Loop SC (CLSC) (Al-Salem et al., 2016). According to Hassanzadeh and Baki (2016), SC networks can be classified into three groups: forward SC, reverse SC, and closed-loop SC. Forward SC aims to provide the customers with a final product via suppliers, manufacturing facilities, distribution centers, and retailers (Mardan et al. 2019), while reverse SC focuses on collecting and recovering returned products from customers (Diabat et al., 2015; Jolai et al., 2020; Bakhshi and Heydari, 2021). CLSC reduces the disposal of end-of-use products and consumes lesser natural resources and energy than manufacturing all-new products (Agrawal et al., 2016). Considering the FLP in a CLSC, Amin and Zhang (2013) proposed a mixed-integer linear programing model is that minimizes the total cost to address a facility location problem in a closed-loop supply chain. The model then was extended to consider environmental factors by weighed sums and e-constraint methods. Kaya and Urek (2016) introduced a mixed-integer non-linear model in order to find the locations for facilities. Jabbarzadeh et al. (2017) proposed a stochastic robust optimization model for the design of a CSLC network as an attempt to minimize the total supply chain cost. A mixed-integer programming was established by Ghadge et al.(2016). Amin & Baki (2017) introduced a bi-objective model to find the best locations for facilities to maximize on-time delivery and total profits. Wu et al. (2018) introduced a fuzzy mixed-integer linear programming model for a CLSC. Zhen et al. (2019) also dealt with uncertainties in demand while addressing the problem of finding suitable locations and scales of facilities in a CLSC. Danesh et al. (2020) proposed a mixed-integer linear programming model to optimize the cost of locating facilities in a CLSC.

The increase in greenhouse gas (GHG) emissions such as CO2 has resulted in climate changes, global warming, and environmental issues (Fareeduddin et al., 2017). Since SC activities are a significant source of these gases, recently, green SC has become one of the most important approaches in supply chain. A green SC that considers the integration of forward and reverse supply chains is called a Green Closed-Loop Supply Chain (GCLSC) (Fareeduddin et al. 2015). The GCLSC achieves excellent work results in reducing energy usage, materials consumption, and air and water pollution (Liu and Yi 2017), and helps industries to reuse the end-of-life products (Chakraborty et al, 2021). Focusing on facility location problems in a GCLSC, Talaei et al. (2016) focused on a multi-product GCLSC by proposing a mixed-integer linear programming model to minimize the total cost. An FLP in a single period single product CLSC was investigated by Aldoukhi and M. Gupta (2020) to minimize the total cost and the carbon emission. Liu et al. (2018) introduced a bi-objective model with uncertain demand in which there are two classes of warehouses. Zhao et al., (2018) addressed a facility location problem in a green closed-loop supply chain with uncertain demand and CO2 emission rate. In order to providemore reliable solutions, they used a risk-averse method. Yang and Chen (2020) proposed a collection center location problem. Zhen et al. (2019) considered two objective functions for CO2 emissions and total operating cost to deal with a FLP in a GCLSC. Yavari and Zaker (2019) focused on a SC of perishable food, using an Iranian dairy factory as the case study.

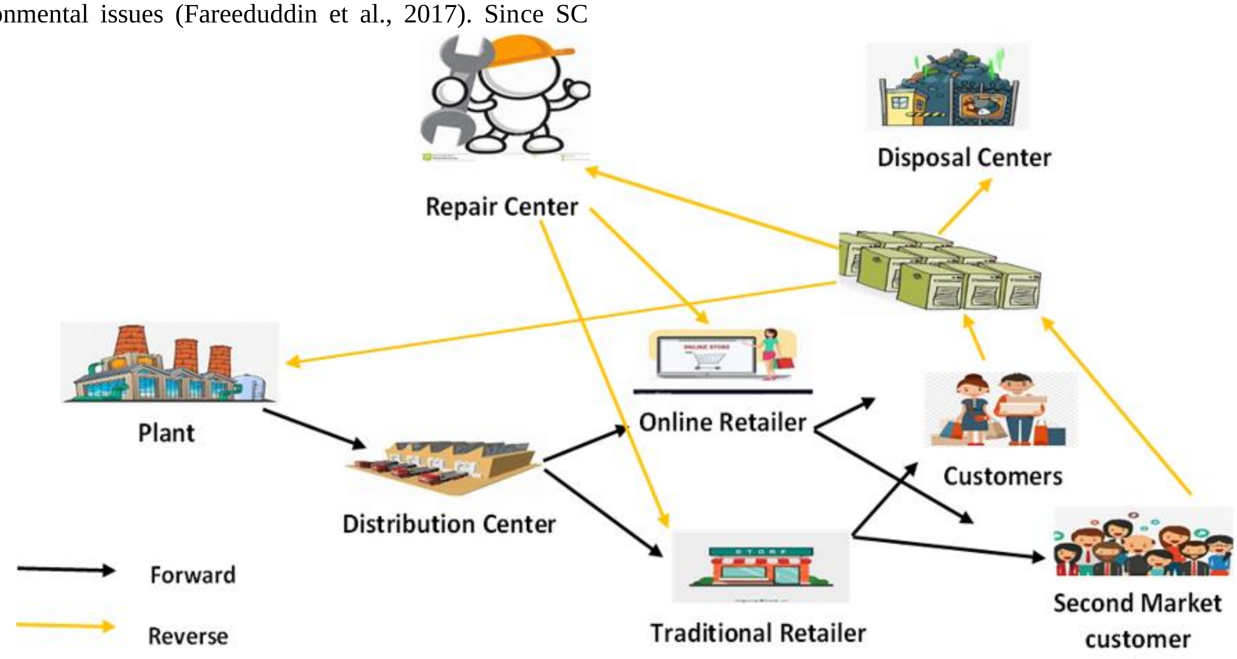


FIGURE 1
THE PROPOSED CLOSED-LOOP SUPPLY CHAIN

Though the importance and profitability, both financially and environmentally, of finding the best location for facilities in GCLSC is undeniable, only a few studies have addressed this issue. Thus, in this paper, we aim to fill the existing gap by proposing a multi-objective model for a network design in a facility location problem in a green closed-loop supply chain to minimize environmental impacts of manufacturing and transportation and maximize the profit. According to the reviewed literature, three main contributions distinguish our work from the others. Firstly, most of the previous works considered the CO_2 emission as a part of their objective function in the form of cost. On the other hand, we defined a separate objective function to minimize the number of greenhouse gases independently and not as a part of our profit objective function. Secondly, as the relevant papers tried to minimize their total cost, we aimed to maximize our profit and determine a reasonable price that is affordable for our customer and results in a fair amount of profit for the system. Finally, according to the pandemic situation caused by the breakout of Covid-19, we considered online retailers and the traditional ones to be considerably more relatable to the current concerns than the previous works.

MODEL DEFINITION

I. Problem description

The CLSSC studied in this paper includes forward supply chain and reverse logistics. In the forward flow, plants produce new products then deliver them to distribution centers, then the products are delivered to traditional and online retailers that were developed to address the recent increase of online shopping derived by the Covid-19 pandemic. Products are divided into two groups, defective ones and non-defective ones. Non-defective products will be distributed by online and traditional retailers in the first market, while the defective ones will be sold to customers of a second market by the same retailers but at a lesser price. Customers transport the used products to collecting centers. In that location, the products are divided into 3 categories. One category is transported to a disposal center, the other to a repair center, and the last one to a plant. Products will be repaired and returned to online/traditional retailers in the repair center. In the plant, products will be recycled and transported to distribution centers. At the same time, the model determines the best location of plants, distribution centers, collecting centers and repair centers. The objectives of this model are minimizing the environmental issues by controlling greenhouse gas emissions and maximizing total revenue.

- *Model assumption*

Model assumptions are as follows:

- This is a single-period model.
- The potential locations of plants, distribution, collecting, and repair centers are not determined.
- All returned products should be collected.
- It is not obligatory to answer all the customers' and second market customers' demands and shortage is acceptable.
- The price of recycled products from customers and second market customers is the same.
- The GHG emission is not only the result of production, but transportation produces GHG too.
- A customer can buy products from both online and traditional retailers at the same time.
- The problem is under capacity constraint (plant, distribution center and collecting center)

II. Mathematical Model

According to the above description and assumption of the problem, the mathematical model for a CLSSC by considering the facility location problem will be presented in detail.

- *Notations*

Sets and Indices:

P = set of plants (1…p... P)
D = set of distribution centers (1 … d… D)
R = set of online retailers (1… r…R)
T = set of traditional retailers (1… t…T)
K = set of customers (1… k…K)
M = set of second market customers (1…m…M)
C = set of collecting centers (1… c …C)
L = set of disposal centers (1… l…L)
I = set of repair centers (1… i… I)
J = set of products (1… j …J)

Parameters

A_{pj} = production cost of product j in plant p.

TR_{pdj} = transportation cost of product j per km between plant p and distribution center d.

$TR_{kcj}, TR_{clj}, TR_{cij}, TR_{cpj}, TR_{rmj}, TR_{tmj}, TR_{mcj}$ $TR_{drj}, TR_{dtj}, TR_{rkj}, TR_{tkj}, TR_{irj}, TR_{itj}$, $= are\ defined\ as\ the\ same\ way\ of\ TR_{pdj}$

α_{1clj} $= the\ percent\ of\ returned\ product\ j\ form\ collecting\ center\ c\ to\ a\ disposal\ center$

α_{2cij} $= the\ percent\ of\ returned\ product\ j\ form\ collecting\ center\ c\ to\ a\ repair\ center$

α_{3cpj} $= the\ percent\ of\ returned\ product\ j\ form\ collecting\ center\ c\ to\ a\ plant$

RE_{kj} $=$ the returned quantity of product j from customer k
REm_{mj} $=$ the returned quantity of product j from second market m
D_{kj} $=$ demand of customer k for product j
D_{mj} $=$ demand of second market m for product j
DI_{pd} $=$ distance between plant p and distribution center d (km)
$DI_{dr}, DI_{dt}, DI_{rk}, DI_{tk}, DI_{kc}, DI_{ci}, DI_{cp}, DI_{cl}, DI_{ir}, DI_{it}, DI_{rm}, DI_{tm}, DI_{mc}$ $=$ are defined as the same way of DI_{pd}
β_{1pj} $=$ emission functor factor in the production of product j in plant p $(\frac{ton}{unit})$
$\beta_{2ab}j$ $=$ emission functor factor in the transportation of product j from location a to b $\left(\frac{ton}{km}\right)$
U^e $=$ upper limit of Green House Gas (GHG) emission.
FC_p $=$ fixed cost of opening plant p.
FC_d, FC_c, FC_i $=$ are defined as the same way of FC_p
CS_j^I $=$ cost saving of product j because of repairs.
CS_j $=$ cost saving of product j because of recycling in a plant.
DC_j $=$ disposal cost of product j.
RC_j $=$ repairing cost of product j.
CAP_{pj} $=$ capacity of plant p for product j.
CAP_{cj} $=$ capacity of collecting center c for product j.
CAP_{dj} $=$ capacity of distribution center d for product j.
CAP_{lj} $=$ capacity of disposal center l for product j
CAP_{ij} $=$ capacity of repair center i for product j
OP_{jr}^O $=$ ordinary price of product j sold by online retailer r.
OP_{jt}^T $=$ ordinary price of product j sold by traditional retailer t.
SP_{jr}^O $=$ price of product j sold by online retailer r to second market.
SP_{jt}^T $=$ price of product j sold by traditional retailer t to second market.
π_{kj} $=$ shortage cost of product j for customer k.
π_{mj} $=$ shortage cost of product j for second market m.
ρ_{pj} $=$ The percent of the defected product j produced in plant p.
B_r^O $=$ Limitation of budget for online retailer r.
B_t^T $=$ Limitation of budget for traditional retailer t.

Variables:

X_{pjd} $=$ quantity of product j sent by plant p for distribution center d.
Y_{kcj} $=$ quantity of returned product j from customer k to the collecting center c.
Ym_{mcj} $=$ quantity of returned product j from second market m to the collecting center c.
DE_{drj}^O = quantity of product j sent from distribution center d to online retailer r.
DE_{dtj}^T = quantity of product j sent from distribution center d to traditional retailer t.
H_{rkj} = quantity of product j sent from online retailer r to customer k.
H_{tkj} = quantity of product j sent from traditional retailer t to customer k.
Hmr_{rmj} = quantity of product j sent from online retailer r to second market m.
Hmt_{tmj} = quantity of product j sent from traditional retailer t to second market m.
γ_{irj} $=$ the fraction of product j repaired by repair center i and returned to online retailer r.
γ_{itj} $=$ the fraction of product j repaired by repair center i and returned to traditional retailer t.
S_{clj} $=$ quanitity of returned product j from collecting center c to disposal center l.
T_{cij} $=$ quanitity of returned product j from collecting center c to repair center i.
F_{cpj} $=$ quanitity of returned product j from collecting center c to plant p.
Sh_{kj} $=$ shortage amount of product j for customer k.
ρ_{dj}^d = The percent of product j which is defective in distribution d's site.
ρ_{rj} =The percent of product j which is defective and is to be sold by online retailer r.

ρ_{tj} = The percent of product j which is defective in and is to be sold by traditional retailer t.

Sh_{mj} = shortage amount of product j for second market m.

DE_{dj} = demand of distribution center d for product j.

Z_d = 1, if a distribution center is located and set up at potential site d, 0, o.w.

Z_p = 1, if a plant is located and set up at potential site p, 0, o.w.

Z_i = 1, if a repair center is located and set up at potential site i, 0, o.w.

Z_c = 1, if a collecting center is located and set up at potential site c, 0, o.w.

***1-1-** Objective Functions*

The proposed objective functions are:

$$\begin{aligned}\text{Min } Z_1 = &\sum_p\sum_j\sum_d \beta_{1pj}X_{pjd} + \sum_p\sum_d\sum_j \beta_{2pdj}DI_{pd}X_{pjd} \\ &+ \sum_d\sum_r\sum_j \beta_{2drj}DI_{dr}DE^{O}_{drj} \\ &+ \sum_d\sum_t\sum_j \beta_{2dtj}DI_{dt}DE^{T}_{dtj} \\ &+ \sum_t\sum_k\sum_j \beta_{2tkj}DI_{tk}H_{tkj} \\ &+ \sum_r\sum_k\sum_j \beta_{2rkj}DI_{rk}H_{rkj} + \sum_k\sum_c\sum_j \beta_{2kcj}DI_{kc}Y_{kcj} + \sum_m\sum_c\sum_j \beta_{2mcj}DI_{mc}Ym_{mcj} \\ &+ \sum_r\sum_m\sum_j \beta_{2rmj}DI_{rm}Hrm_{rmj} + \sum_t\sum_m\sum_j \beta_{2tmj}DI_{tm}Htm_{tmj} + \sum_c\sum_l\sum_j \beta_{2clj}DI_{cl}S_{clj} \\ &+ \sum_c\sum_p\sum_j \beta_{2cpj}DI_{cp}F_{cpj} + \sum_c\sum_i\sum_j \beta_{2cij}DI_{ci}\ T_{cij} + \sum_i\sum_r\sum_j \beta_{2irj}DI_{ir}\gamma_{irj}T_{cij} \\ &+ \sum_i\sum_t\sum_j \beta_{2itj}DI_{ir}\gamma_{itj}\ T_{cij}\end{aligned}$$

$$\begin{aligned}Max\ Z_2 = &\Big[\textstyle\sum_r\sum_k\sum_j OP^{O}_{jr}\left(H_{rkj}\right) + \sum_t\sum_k\sum_j OP^{T}_{jt}\left(H_{tkj}\right) + \sum_c\sum_i\sum_j CS^{i}_{j}\ T_{cij} + \sum_c\sum_p\sum_j CS_j F_{cpj} + \\ &\textstyle\sum_r\sum_m\sum_j SP^{O}_{jr}\left(Hmr_{rmj}\right) + \sum_t\sum_m\sum_j SP^{T}_{jr}\left(Hmt_{tmj}\right)\Big] - \Big[\sum_p\sum_j\sum_d A_{pj}X_{pjd} + \sum_p Z_p\,.FC_p + \sum_i Z_i.FC_i + \\ &\textstyle\sum_c Z_c\,.FC_c + \sum_d Z_d\,.FC_d + \sum_p\sum_j\sum_d TR_{pdj}DI_{pd}X_{pdj} + \sum_r\sum_j\sum_d TR_{drj}DI_{dr}DE^{O}_{drj} + \sum_t\sum_j\sum_d TR_{dtj}DI_{dt}DE^{T}_{dtj} + \\ &\textstyle\sum_r\sum_k\sum_j TR_{rkj}DI_{rk}H_{rkj} + \sum_t\sum_k\sum_j TR_{tkj}DI_{tk}H_{tkj} + \sum_k\sum_c\sum_j TR_{kcj}DI_{kc}Y_{kcj} + \sum_c\sum_l\sum_j TR_{clj}\ DI_{cl}\ S_{clj} + \\ &\textstyle\sum_c\sum_i\sum_j TR_{cij}\ DI_{ci}T_{cij} + \sum_c\sum_p\sum_j TR_{cpj}\ DI_{cp}\ F_{cpj} + \sum_r\sum_m\sum_j TR_{rmj}DI_{rm}Hrm_{rmj} + \sum_t\sum_m\sum_j TR_{tmj}DI_{tm}Htm_{tmj} + \\ &\textstyle\sum_m\sum_c\sum_j TR_{mcj}DI_{mc}Y_{mcj} + \sum_i\sum_r\sum_j\sum_c TR_{irj}\ DI_{ir}\ \gamma_{irj}T_{cij} + \sum_i\sum_t\sum_j\sum_c TR_{itj}\ DI_{it}\ \gamma_{itj}T_{cij} + \sum_k\sum_j \pi_{kj}Sh_{kj} + \\ &\textstyle\sum_m\sum_j \pi_{mj}Sh_{mj} + \sum_c\sum_l\sum_j\ DC_j\ S_{clj} + \sum_c\sum_i\sum_j RC_jT_{cij}\Big]\end{aligned}$$

- *Model Constrains*

$$\sum_p X_{pjd} \geq DE_{dj} \quad \forall d,j \qquad (1)$$

$$\sum_d X_{pjd} + \sum_c F_{cpj} \leq Z_p.CAP_{pj} \quad \forall p,j \qquad (2)$$

$$\sum_k Y_{kcj} + \sum_m Ym_{mcj} \leq Z_c \, .CAP_{cj} \qquad \forall c, j \tag{3}$$

$$\sum_c T_{cij} \leq Z_i CAP_{ij} \qquad \forall i, j \tag{4}$$

$$\sum_c S_{clj} \leq CAP_{lj} \qquad \forall l, j \tag{5}$$

$$Z_d . CAP_{dj} \geq \sum_p X_{pdj} \qquad \forall d, j \tag{6}$$

$$DE_{dj} = \sum_r DE^O_{drj} + \sum_t DE^T_{dtj} \tag{7}$$

$$\sum_j \sum_d SP^T_{jt} \, DE^T_{dtj} \leq B^T_t \qquad \forall t \tag{8}$$

$$\sum_j \sum_d SP^O_{jr} \, DE^O_{drj} \leq B^O_r \qquad \forall r \tag{9}$$

$$\sum_d DE^O_{drj} + \sum_i \sum_c \gamma_{irj} T_{cij} \geq \sum_k H_{rkj} + \sum_m Hrm_{rmj} \qquad \forall \, r, j \tag{10}$$

$$\sum_d DE^T_{dtj} + \sum_i \sum_c \gamma_{itj} T_{cij}$$
$$H_{tkj}$$
$$\geq \sum_k \sum_m Htm_{tmj} \qquad \forall \, j, t \tag{11}$$

$$Sh_{kj} = D_{kj} - \sum_r H_{rkj} - \sum_t H_{tkj} \qquad \forall k, j \tag{12}$$

$$Sh_{mj} = D_{mj} - \sum_r Hrm_{rmj} - \sum_t Htm_{tmj} \qquad \forall m, j \tag{13}$$

$$RE_{kj} \leq \sum_r H_{rkj} + \sum_t H_{tkj} \qquad \forall k, j \tag{14}$$

$$REm_{mj} \leq \sum_r Hrm_{rmj} + \sum_t Htm_{tmj} \qquad \forall m, j \tag{15}$$

$$\rho_{dj} = \frac{\sum_p \rho_{pj} X_{pjd}}{\sum_p X_{pjd}} \qquad \forall \, j, d \tag{16}$$

$$\rho_{rj} = \frac{\sum_d \rho_{dj} DE^o_{drj}}{\sum_d DE^o_{drj}} \qquad \forall \, j \, , r \tag{17}$$

$$\rho_{tj} = \frac{\sum_d \rho_{dj} DE^T_{dtj}}{\sum_d DE^T_{dtj}} \qquad \forall \, j \, , t \tag{18}$$

$$\sum_r \sum_m Hrm_{rmj} \leq \sum_r \rho_{rj} \sum_d DE^o_{drj} \qquad \forall \, j \tag{19}$$

$$\sum_t \sum_m Htm_{tmj} \leq \sum_t \rho_{tj} \sum_d DE^T_{dtj} \qquad \forall \, j \tag{20}$$

$$\sum_c Y_{kcj} = RE_{kj} \qquad \forall k, j \tag{21}$$

$$\sum_c Ym_{mcj} = REm_{mj} \qquad \forall m, j \tag{22}$$

$$S_{clj} = \alpha_{1clj} \Big(\sum_k Y_{kcj} + \sum_m Ym_{mcj} \Big) \qquad \forall c, l, j \tag{23}$$

$$T_{cij} = \alpha_{2cij} \Big(\sum_k Y_{kcj} + \sum_m Ym_{mcj} \Big) \qquad \forall c, i, j \tag{24}$$

$$F_{cpj} = \alpha_{3cpj} \Big(\sum_k Y_{kcj} + \sum_m Ym_{mcj} \Big) \qquad \forall c, p, j$$

$$\sum_p \sum_j \sum_d \beta_{1pj} X_{pjd} + \sum_p \sum_d \sum_j \beta_{2pdj} DI_{pd} X_{pjd} + \sum_d \sum_r \sum_j \beta_{2drj} DI_{dr} DE^{O}_{drj} + \sum_d \sum_t \sum_j \beta_{2dtj} DI_{dt} DE^{T}_{dtj} + \sum_r \sum_k \sum_j \beta_{2rkj} DI_{rk} H_{rkj} + \sum_r \sum_m \sum_j \beta_{2rmj} DI_{rm} Hrm_{rmj} + \sum_t \sum_m \sum_j \beta_{2tmj} DI_{tm} Htm_{tmj} + \sum_m \sum_c \sum_j \beta_{2mcj} DI_{mc} Ym_{mcj} + \sum_k \sum_c \sum_j \beta_{2kcj} DI_{kc} Y_{kcj} + \sum_i \sum_r \sum_j \beta_{2irj} DI_{ir} \gamma_{irj} T_{cij} + \sum_i \sum_t \sum_j \beta_{2itj} DI_{ir} \gamma_{itj} T_{cij} + \sum_c \sum_l \sum_j \beta_{2clj} DI_{cl} S_{clj} + \sum_c \sum_p \sum_j \beta_{2cpj} DI_{cp} F_{cpj} + \sum_c \sum_i \sum_j \beta_{2cij} DI_{ci} T_{cij} + \sum_t \sum_k \sum_j \beta_{2tkj} DI_{tk} H_{tkj} \leq U^e \quad (25)$$

$$\sum_r \gamma_{irj} + \sum_t \gamma_{itj} = 1 \qquad \forall i, j \quad (26)$$

$$Z_p, Z_i, Z_c, Z_l \in \{0,1\} \qquad \forall p, i, c, l \quad (27)$$

$$X_{pjd}, Y_{kcj}, Ym_{mcj}, Hmr_{rmj}, Hmt_{tmj}, DE^{O}_{rdj}, DE^{T}_{tdj}, S_{clj}, T_{cij}, F_{cpj}, H_{rkj}, Sh_{kj}, \rho^{d}_{dj}, \rho_{rj}, \rho_{tj}, Sh_{mj}, DE_{dj}, H_{tkj}, \gamma_{irj}, \gamma_{itj} \geq 0 \quad \forall p, j, d, c, t \quad (28)$$

The first objective function minimizes the GHG emission, and the second one maximizes the profit. Constraint (1) ensures that the total number of each manufactured product for each distribution center is equal to or greater than its demand. Constraints (2) to (6) are capacity constraints for plants, collecting centers, repair centers, disposal centers, and distribution centers. Constraint (7) ensures that the total demand of online and traditional retailer for product j should be equal to the total demand of distribution center for product j. Constraints (8) and (9) show that the total price of the bought products by traditional retailer t and online retailer r, respectively should be less than their budget limit. Constraints (10) and (11) show that the summation of demand of online/traditional retailers for product j and the quantity of returned product j from repair center to the online/traditional retailers is equal to or greater than the quantity of product j sent to ordinary customers and second market customers. Constraint (12) enforces that the shortage amount of product j for customer k is equal to the difference of the demand of customer k for product j and the summation of the quantity of product j sent from online and traditional retailers to customer k. Constraint (13) enforces that the shortage amount of product j for second market customer m is equal to the difference of the demand of second market customer m for product j and the summation of the quantity of product j sent from online and traditional retailer to second market customer m.

Constraint (14) shows that the return of product j from customer k is less than the summation of the product sent from online and traditional retailers to customer k. Constraint (15) shows that the return of product j from second market customer m is less than the summation of the products sent from online and traditional retailers to the second market customer m. Constraints (16) to (18) show the percent of defective products in the distribution center, online and traditional retailer. Constraints (19) and (20) ensures that the number of product j sent from online/traditional retailer to the second market customers is less than the number of defective products which online/traditional retailers have. Constraints (21) and (22) shows that the total number of product j sent from customer k/second market customer m respectively, to the collecting center c is equal to the total number of returned product j from customer k/second market customer m. Constraints (23) to (25) ensures that the number of product j sent from collecting center to the disposal center, repair center, and plant (respectively) is a fraction of the total number of product j returned to the collecting center c from customer k and second market customer m. Constraint (26) enforces that the total amount of GHG emission is less than the distinct upper limit. Constraint (27) ensures that the summation of the total fraction of product j sent from repair center i to the online and traditional retailers is equal to one. Constraint (28) shows the binary nature of decision variables, while Constraint (29) preserves the non-negativity restriction on the decision variables.

SOLUTION APPROACH

In this paper, firstly, we used an exact technique, GAMS software, to address the problem in small and medium-sized. Since the objective functions of our model have different scales, in order to aggregate them into one objective function and solve the model, we needed to normalize our objectives. In this regard, the Lpmetric technique was used in which an efficient normalizing function is proposed for aggregating different objectives with different scales (Isaloo & Paydar, 2020).

According to this rigorous multi-objective technique for making a combined dimensionless objective, there are three steps to solve our problem. In the first step, the optimal sequences for the first and second objectives should be found. Suppose Z_1^* and Z_2^* as the best value of the first and second objectives. The LP-metric objective will be constructed as equation 30:

$$Z_{Lpmetric} = w_1\left(\frac{Z_1 - Z_1^*}{1 + Z_1^*}\right) + w_2\left(\frac{Z_2 - Z_1^*}{1 + Z_2^*}\right) \tag{30}$$

Where w_1 and w_2 are the weight of each objective function and determined by the decision maker (Aryanezhad et al., 2009).

In order to solve the model in large size, we used GOA which was proposed in 2017. It is a meta-heuristic method which is inspired from grasshopper swarms' behavior. GOA is a population-based algorithm that seeks to find optimal solutions Swarm intelligence techniques by mimicking the grasshoppers' behavior and their movements for finding food sources (Masoumi et al., 2021; Momeni et al., 2019). GOA is a nature-inspired algorithm. The process of finding the best solution in nature inspired algorithm is making balance between exploration and exploitation. In exploration, the algorithm tends to have a randomized behavior, so the solutions are changed significantly. However, in exploitation, the algorithm searches locally and the solution changes are small (Saremi et al., 2017).

In GOA, the element of social interaction is the main search mechanism which is calculated by:

$$S_i = \sum_{j=1,j\neq i}^{N} s(d_{ij})\widehat{d_{ij}} \tag{31}$$

d_{ij} calculates the distance between grasshoppers by $|x_j - x_i|$, S is a function which calculates social forces and $\widehat{d_{ij}} = \frac{x_j - x_i}{d_{ij}}$. In this equation, the direction of the movement of the grasshopper in the group is determined by function s as follows:

$$s(r) = f\, e^{\frac{-r}{l}} - e^{-r} \tag{32}$$

This function creates the attraction and repulsion forces between the grasshoppers, so changing the parameters of function s significantly affects the swarm behavior. Therefore, the following model is designed to an optimization algorithm:

$$X_i^d = c\left(\sum_{j=1,i\neq j}^{N} c\,\frac{ub_d - lb_d}{s}\, s\left(\left|x_j^d - x_i^d\right|\right)\frac{x_j - x_i}{d_{ij}}\right) + \hat{T}_d \tag{33}$$

ub_d and lb_d are the upper and lower bound of the d-th dimension, respectively. The parameters $\hat{T}_d$ and c are considered as controller parameters in reaching the goal.

$$c = c_{max} - l\,\frac{c_{max} - c_{min}}{L} \tag{34}$$

L and l show the maximum number of iteration and the current iteration respectively. The value of c_{max} is 1 and c_{min} is 0.00001.

This algorithm can solve complex models and effectively finds optimal solutions for complex problems by making initial solutions continuously to generate discrete variables (Rezaei, et al., 2021). However, GOA is an optimization over continuous spaces, so to ensure that exploration and exploitation are working properly in discrete spaces, initial solutions should be created continuously, and then continues variables will be converted to discrete ones. For example, to produce a binary variable Z_p, at first, we should produce a continuous vector between 0 and 1 with P elements. Then the vector will be sorted ascendingly and exploit the indices vector from that. This vector will then show a random combination of numbers between 1 and P. A random number between 1 and P will be selected, which we call RN. Then the first RN elements of the sorted coefficient vector will be chosen to establish plants. So, in every iteration, the random permutation and RN will be changed, ensuring that we consider all possible answers and combinations. In fact, the first vector is a grasshopper which tries to find the best balance between exploration and exploitation in each iteration. The following figure can better illustrate the process:

A random continuous vector:

RC	1	2	3	4
UNIF (0,1)	0.5	0.2	0.1	0.4

Sorted Vector:

RC	3	2	4	1
UNIF (0,1)	0.1	0.2	0.4	0.5

A random permutation of RC when RN=3:

3	2	4	1

FIGURE 2
A SCHEMATIC VIEW OF VARIABLE CREATION IN GOA

In the example, which is shown in figure 2, P is 4, so we have 4 random numbers between zero and 1. Now, RN should be a random number between 1 and P (P=4). Let's assume that in the current iteration RN is 3, so 3 first elements of the sorted vector will be chosen as is highlighted in the figure. The chosen elements are indices of the plants, so in this example, in the current iteration plants 3, 2 and 4 will be established. In the next iterations, as the RN and random numbers will be different, the set of established plants will be also different which ensures that we are considering all possible solutions.

In this method, we also try to produce the variables so that more constraints are satisfied. For instance, after producing X_{pjd} and producing continuous numbers between zero and 1 in a $p \times j \times d$ space, we can calculate ρ_{dj} by considering the constraint number 16 in the way that by producing this variable the constraint be satisfied simultaneously. Obviously, by changing the grasshopper of the first 0 and 1 continuous matrix, ρ_{dj} will be changed which means that we are searching for all possible answers in response space.

I. Computational experiments

In this paper, a numerical example in small and medium-sized is discussed and solved with exact methods by GAMS software. To gain better and more reliable answers which are more realistic, the model should be solved in a large size. To increase the size of the problem, we should allocate greater numbers to the sets. For example, more customers, and plants. However, because of the complexity of the model in large size, using exact methods takes too much time and is not suitable for solving the model. Thus, there is the need to use an appropriate meta-heuristic algorithm, namely Grasshopper Optimization Algorithm (GOA to address the problem in a large size. Noteworthy is to mention that we used BARON solver for GAMS software to solve our model in small and medium size and MATLAB software was used to implement GOA algorithm. Regarding both the exact and metaheuristic approach, the whole solving processes were implemented on ASUS K45VD Intel (R) Core (TM) i5-3210M CPU@ 2.50GHz 6 GB RAM in MATLAB R2018a.

II. Results of the small and medium-size problem

The assumed value of parameters for the small problem size is indicated in table 1 of the supplementary file. For the small size of the problem, the set size of the plants is 3, the set size of the customers is 5, the set size of the second market customers is 3 and the rest of the sets are 2. In the medium-size problem, however, the size of the customers set is 10, second market customers set is 5, and the size of the rest of the sets had been doubled compared to the small size. Table 2 of the supplementary file shows the assumed value of parameters for the medium-size problem. We also proposed a large size problem by 50% increase in the parameters of the medium size problem. The assumed parameters are in table 3 of the supplementary section.

As we are working with a multi-objective model, we used the LP-metric method to turn the objective functions of ours into a single one. Different weights are assigned to the objective functions in the LP-metric formula, and then a single final value is achieved. The weights show the importance of each objective function. In this problem, we assigned 0.35 to the first objective function and 0.65 to the second one since the second objective function is considered to be more critical. These weights may change based on the managers' desire. The results of solving the model in small size with GAMS software are illustrated in Table 1 and

Table **2**.

TABLE 1
RESULTS OF SOLVING THE PROBLEM IN SMALL SIZE WITH GAMS

Z_1^{Max}	Z_1^{Min}	Z_2^{Max}	Z_2^{Min}	Z_3
70000	5878.920	829377	-2580000	0.024

Variable (V1)	Value (V2)	V1	V2	V1	V2	V1	V2	V1	V2
X_{112}	45	Y_{221}	8	Ym_{121}	8	Htm_{23}	6	Ht_{25}	22
X_{121}	13	Y_{222}	21	Ym_{211}	2	Htm_{21}	11	Ht_{25}	10
X_{211}	46	Y_{312}	20	Ym_{212}	10	Htm_{22}	10	ρ_{21}^{d}	0.15
X_{212}	33	Y_{321}	30	Ym_{321}	8	Htm_{23}	8	ρ_{11}^{T}	0.15
X_{222}	112	Y_{421}	29	Ym_{322}	8	Ht_{122}	24	ρ_{12}^{T}	0.13
Y_{121}	40	Y_{422}	23	Ht_{112}	26	Ht_{221}	30	ρ_{22}^{T}	0.14
Y_{122}	26	Y_{521}	22	Ht_{122}	24	Ht_{231}	30	ρ_{12}^{d}	0.14
Y_{211}	22	Y_{522}	10	Ht_{211}	40	Ht_{232}	20	sh_{12}	85
Y_{212}	3	$Ym_{12:}$	11	Htm_{21}	6	Ht_{242}	23	sh_{22}	55
sh_{32}	37	sh_{42}	77	sh_{51}	38.36	sh_{52}	66	Y_{121}^{mc}	8
Y_{122}^{mc}	11	Y_{221}^{mc}	2	Y_{222}^{mc}	10	Y_{321}^{mc}	8	Y_{322}^{mc}	8

TABLE 2
THE VALUES OF THE SMALL SIZE OBJECTIVE FUNCTIONS IN MINIMUM AND MAXIMUM MODES

Z_1^{Max}	Z_1^{Min}	Z_2^{Max}	Z_2^{Min}	Z_3
7503.372	3821.721	1819.706	-214981.39	0.117

As mentioned earlier, because of working with a multi-objective model, the Lpmetric method is used to achieve a single objective value (Z_3). ${Z_1}^{max}$ and ${Z_1}^{min}$ result when the problem is solved only with the first objective function in two Max and Min modes. Also, ${Z_2}^{max}$ and ${Z_2}^{min}$ are the results of the problem when it is solved only with the second objective value in two Max and Min modes. Finally, Z_3 is the single final answer to the problem in Lpmetric method. The results show that plants are located in locations 1, 2, and 3. Repair centers, collecting centers, and disposal centers are located in locations1 and 2. The most important factor in this problem is the benefit amount. The benefit amount based on the random parameters and calculated variables is 120186.168 thousand Tomans, and the amount of GHG emission is 11485.297 Ton. The rest of the variables are shown in the tables above. Figure 3 shows the small size Pareto-optimal solution of the proposed multi-objective model.

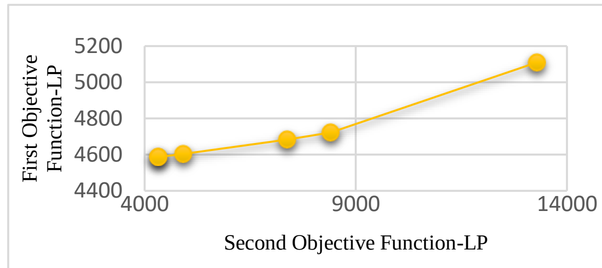


FIGURE 3
THE PARETO-OPTIMAL SOLUTION OF A TWO-OBJECTIVE MODEL IN THE SMALL-SIZED PROBLEM

In the medium-size problem, the maximum and minimum amount of GHG emission is 70000 and 5878.920 tons, respectively. In the same way, 838911.875 and -2580000 thousand tomans are the benefit values in max and min modes. The value of the Lpmetric objective function is 0.024. The managers' final decision about their company is highly dependent on the weight which they assign to each objective function. Based on the goals of the managers and their companies, the objective functions can get different weights. Hence, the Pareto figure is a handy tool for them to estimate the probable effects of their different possible decisions on the company.The results of solving the model in medium size with GAMS software is illustrated in **Error! Reference source not found.** and

Table **3**.

TABLE 3
RESULTS OF SOLVING THE PROBLEM IN MEDIUM SIZE WITH GAMS

Variable (V1)	Value (V2)	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
Z_1	37586.737	Y_{214}	39	Y_{714}	26	Ym_{613}	5	Htm_{342}	2	Ht_{2111}	75
Z_2	1489511.70	Y_{314}	34	Y_{843}	32	Ym_{741}	10	Htm_{353}	1	Ht_{322}	75
X_{521}	293	Y_{341}	39	Y_{844}	34	Ym_{744}	9	Ht_{173}	72	Ht_{332}	32
X_{522}	155	Y_{434}	28	Y_{1011}	34	Ym_{834}	9	Ht_{183}	72	Ht_{342}	71

X_{523}	219	Y_{523}	39	Y_{1012}	35	Htm_{114}	1	Ht_{221}	74	Ht_{352}	84
X_{532}	225	Y_{544}	36	Y_{1041}	37	Htm_{112}	4	Ht_{251}	88	Ht_{382}	85
X_{541}	114	Y_{542}	29	Ym_{121}	6	Htm_{123}	3	Ht_{261}	86	Ht_{392}	77
X_{543}	153	Y_{631}	29	Ym_{124}	5	Htm_{134}	1	Ht_{271}	79	Ht_{3102}	80
X_{621}	9	Y_{632}	40	Ym_{241}	9	Htm_{154}	1	Ht_{281}	84	Ht_{3122}	87
X_{622}	91	Y_{634}	28	Ym_{341}	9	Htm_{183}	5	Ht_{291}	85	Ht_{3142}	88
Y_{121}	39	Y_{712}	27	Ym_{343}	7	Htm_{192}	9	Ht_{2101}	74	T_{121}	295
Y_{124}	33	Y_{713}	26	Ym_{444}	2	Htm_{193}	3	Ht_{2111}	75	T_{122}	203
T_{123}	224	T_{124}	85	T_{331}	243	T_{332}	262	T_{333}	251	T_{334}	265
T_{411}	49	T_{442}	175	T_{443}	108	T_{444}	219	Hrm_{351}	9	γ^{r}_{214}	0.918
γ^{r}_{331}	0.036	γ^{t}_{113}	0.98	γ^{t}_{114}	0.56	γ^{t}_{121}	1	γ^{t}_{123}	0.02	γ^{t}_{124}	0.028

TABLE 4
SOLUTIONS OBTAINED BY GOA AND GAMS IN SMALL AND MEDIUM SIZE

	GAMS (Small size)	GOA (Small size)	Gap level	GAMS (Medium size)	GOA (Medium size)	Gap level	Mean gap level
Objective 1	4604.10	4696.64	2.01%	11302.90	11449.84	1.3%	1.65%
Objective 2	4916.51	4857.51	1.2%	831096.57	814474.65	2%	1.60%

TABLE 6
PARETO SMALL SIZE PROBLEM WITH GOA AND GAMS

	GAMS		GOA		GAP	
2nd objective	1st objective	2nd objective	1st objective	2nd objective	1st objective	2nd objective
4270.488	1.7%	1.28%	4665.026	4270.488	1.7%	1.28%
4265.296	1.9%	1.4%	4674.199	4265.296	1.9%	1.4%
4744.429	2.2%	2.35%	4800.969	4744.429	2.2%	2.35%
7305.674	1.16%	0.94%	4737.892	7305.674	1.16%	0.94%
8251.288	2.62%	1.9%	4846.919	8251.288	2.62%	1.9%
12926.57	1.3%	2.7%	5176.773	12926.57	1.3%	2.7%

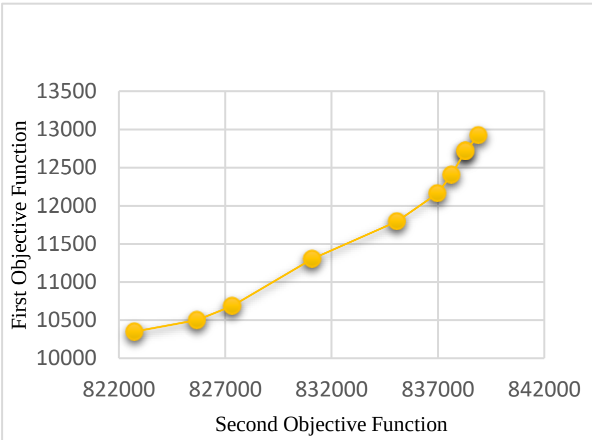


FIGURE 4
THE PARETO-OPTIMAL SOLUTION OF A TWO-OBJECTIVE MODEL IN THE MEDIUM-SIZED PROBLEM

Figure 4 shows the Pareto-optimal solution of the proposed multi-objective model in medium size.

III. Comparative study of solution methods

The following tables provide a comparison between the solutions obtain by the exact and meta-heuristic method. Then the gap between the results of the mentioned methods is estimated. According to

TABLE 4, the gap between the results of GOA and GAMS is almost less than 2% for both small and medium size problem. This gap number proves that this metaheuristic algorithm has an acceptable level of efficiency for solving the problem in small and medium size.

In Table 6, a comparison between the results of the small-size problem solved with exact and meta-heuristic method is shown. This time, the problem is solved six times with different weights assigned to the objective functions to evaluate the efficiency of the GOA method. The results show less than a 3% gap between the results of exact and metaheuristic method.

The comparisons and gaps obtained by solving the problem several times prove the efficiency and applicability of the GOA method to solve the proposed model in the small and medium size. As mentioned earlier, GAMS is not a suitable tool to solve the problem in large size as using exact methods takes too much time. Noteworthy is to mention that the small size problem is solved by Gams in 03:25, and it is solved by GOA in 00:20. Moreover, the medium size problem is solved by Gams and GOA in order in 5:56 and 00:37. This data shows that the increasing size of the problem causes the time of solving the problem by GAMS to boom exponentially. Thus, taking into account the efficiency of the GOA method, for problems with a large size, GAMS is not an appropriate solution method, and we could use GOA by acceptable gap level. Additionally, convergence figures are also shown below to prove the efficiency of using the GOA for large size problem.

Figure 5 shows GOA's performance for the first objective (without other objectives) in small and scale. This objective minimizes the GHG emission. The performance of GOA for the second objective function which maximizes the benefit is shown in figure 6.

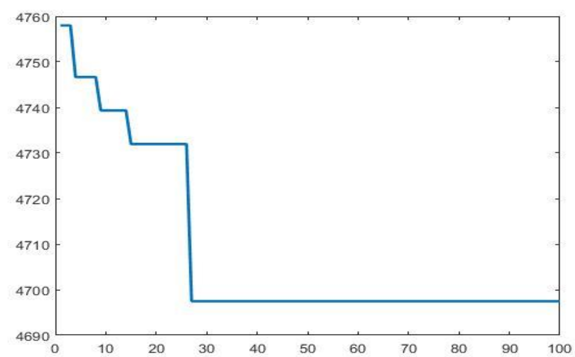


FIGURE 5
FIRST OBJECTIVE CONVERGENCE DIAGRAMS

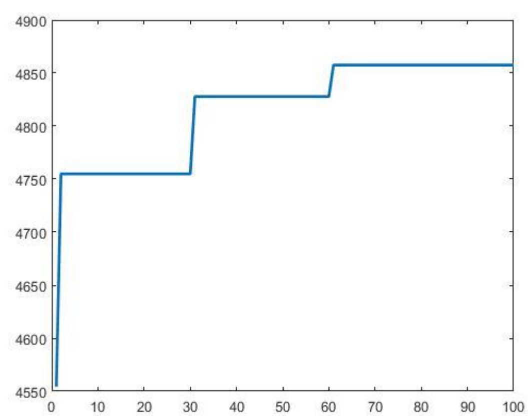


FIGURE 6
SECOND OBJECTIVE CONVERGENCE DIAGRAMS

Table 5: Results of solving the problem in large size with GOA.

Variable (V1)	Value (V2)	V1	V2	V1	V2	V1	V2	V1	V2
X_{151}	159	Y_{251}	45	Ym_{122}	3	T_{134}	229	T_{431}	176
X_{152}	110	Y_{253}	57	Ym_{333}	10	T_{341}	228	T_{433}	254
X_{153}	223	Y_{254}	56	Ym_{335}	10	T_{342}	279	γT_{115}	0.372
X_{154}	295	Y_{255}	47	Ym_{544}	10	T_{344}	214	γT_{141}	0.218
X_{334}	166	Y_{341}	54	Ym_{631}	9	T_{345}	224	γT_{211}	0.412
Y_{121}	58	Y_{342}	55	T_{111}	276	T_{352}	292	Z_1	24880.830
Y_{122}	50	Y_{343}	55	T_{112}	230	T_{422}	234	Z_2	1781274.501
Y_{123}	55	Y_{521}	47	T_{115}	263	T_{423}	228	Z_3	0.085
Y_{222}	50	Ym_{121}	7	T_{135}	282	T_{425}	235	Htm_{114}	70
Ht_{221}	83	Ht_{231}	65	Ht_{241}	67	Ht_{251}	78	Ht_{261}	82
Ht_{271}	80	Ht_{281}	78	Ht_{291}	60	Ht_{2101}	61	Ht_{2111}	78
Ht_{311}	58	Ht_{321}	63	Ht_{341}	72	Ht_{351}	69	Ht_{371}	68

As the result of solving the problem in small and medium sizes with GOA proved its applicability, we used this method to solve a large size problem as an example. The large size problem has 7 plants, 15 customers, 6 second market customer and the rest of the set values are 5. All the data regarding large size problem parameters can be find in the third table of supplementary file.

The results of solving the large size problem with GOA is shown in table 7. Based on the results, plants are established in all the locations expect location number 4 and 7. Distribution centers are established in locations 2,3 and 5. Collecting centers are established in all the locations expect location number 2 and finally repair centers are established in all the locations 1 to 5. The total GHG emitted in this time is 24880.830 ton which shows that more products are returned and use of recycling and repairing process is increased. The increase in return of products is visible in larger value of Ys in table 7. The company's total benefit is 1781274.501 thousand toman which is larger than the benefit it gains in small and medium size, since in the large size there are more customers. Another noteworthy point is that the number of defective products sold to second market is increased, which will decrease the loss of plants and is environmentally friendly. It can be another reason that GHG emission is decreased in large size problem. Other variables are shown in table 7.

SENSITIVITY ANALYSIS

Reducing and increasing some parameters can affect the results. In this regard, we chose customers' demand, second arket customers' demand, online and traditional retailers' price and the percent of defective products to analyze the sensitivity of the objective functions to the different values. The model is resolved in different situations for each parameter. Then, the effects of changing the parameters on the objective functions and other parameters are shown in the figures.

In Figure 7, the total quantity of demand of the second market is changed from 53 to 143, and its effects on the total quantity of the second markets' shortage is estimated. Based on the figure, the increase in the demand causes the increase in shortage, since plants have limited production capacity and additionally only a specific percent of the produced products will be sent to the second markets.

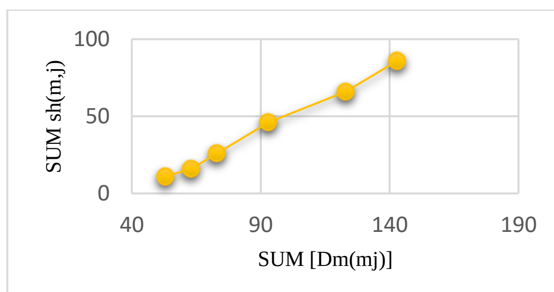


FIGURE 7
DEMAND AND SHORTAGE QUANTITY OF THE SECOND MARKET

Based on Figure 8, the increase in the demand quantity of the second market entices plants to produce more. This increase in production and the transportations required to send the products to the customers will produce more pollution which will increase the value of the first objective function. This paper considered a limitation for the GHG emission, so after a while, the value of the first objective function cannot be increased by increasing the demand.

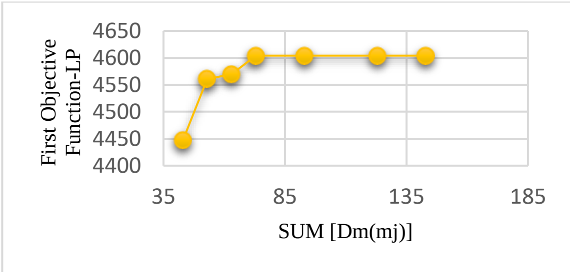


FIGURE 8
DEMAND QUANTITY OF THE SECOND MARKET AND THE FIRST OBJECTIVE FUNCTION

Error! Reference source not found. Error! Reference s ource not found shows that the increase in demand primarily increases the benefit drastically since the company will sell more products which provide it with more money. On the other hand, the more a company produces products, the more its expenses (production, transportation, and shortage) will be. Additionally, every plant has a limit in its production capacity, so it only can answer the demand quantities which are lower than its capacity limitation. So, if the demand quantity exceeds the plant's limitation, the shortage quantity and shortage expenses will be increased. Therefore, the continuation in the demand increase will decrease the benefit after a while.

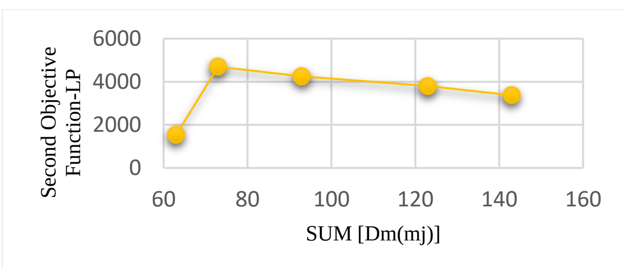


FIGURE 9
DEMAND QUANTITY OF THE SECOND MARKET AND THE SECOND OBJECTIVE FUNCTION

As it was mentioned before, the main source of a chain's benefit is selling products. Selling products is directly dependent on customers' demand. So. When the quantity of demand is low, the benefit is low and even can be negative. Increasing the demand can increase the benefit. As Figure 10 shows, the increase in demand to 800 will increase the benefit. However, after that point, due to several reasons such as shortage, limited capacity, and transportation, the expenses will be increased, and the value of second objective function will decrease.

Demand increase entices plants to produce more and transfer the products to customers, which increases the GHG emission. However, after a while, the plant will meet its capacity limitation and cannot produce more, so there will be less production and less transportation, so less GHG emission. It is all shown in Figure 11 .

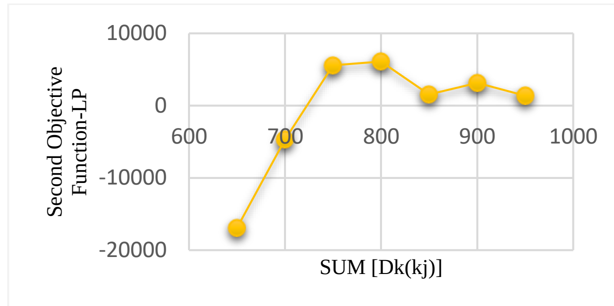


FIGURE 10
DEMAND QUANTITY OF CUSTOMERS AND THE SECOND OBJECTIVE FUNCTION

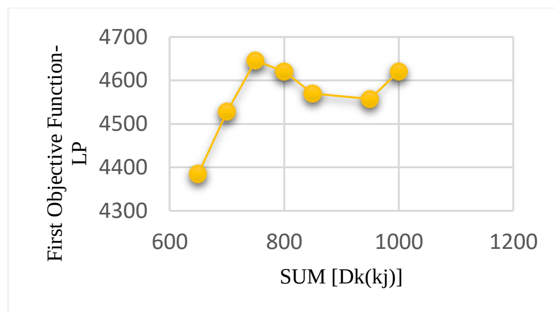


FIGURE 11
DEMAND QUANTITY OF CUSTOMERS AND FIRST OBJECTIVE FUNCTION

Obviously, by increasing the demands, the quantity of shortage will be increased due to the limited capacity of plants Figure 12 is showing the same thing too. Since when customers need more products, the plants try to produce more, so X(pj) will be increased to its capacity's upper bound, and after that quantity, the summation of X(pj) which shows the amount of production of product p by plant j is fixed (Figure 13).

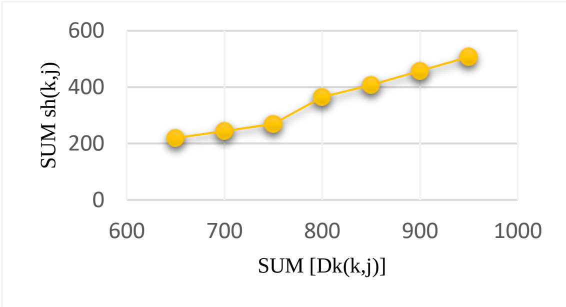


FIGURE 12
DEMAND QUANTITY OF CUSTOMERS AND SHORTAGE

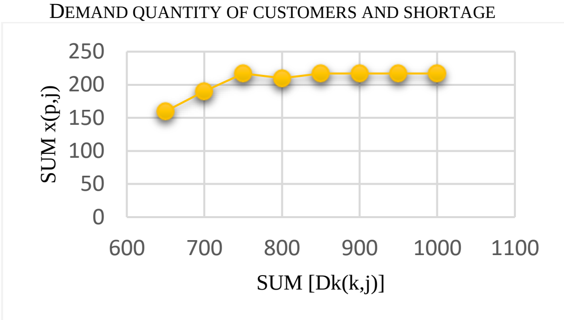


FIGURE 13
DEMAND OF CUSTOMERS AND THE QUANTITY OF PRODUCED PRODUCTS

In Figure 14, when traditional retailers increase their selling prices, the customers will keep buying the products for a while. So, plants will produce more which increase the GHG emission. Nevertheless, after a specific level of increase in the prices, customers will stop buying the products for several reasons such as high price; so, there will be less production and less pollution.

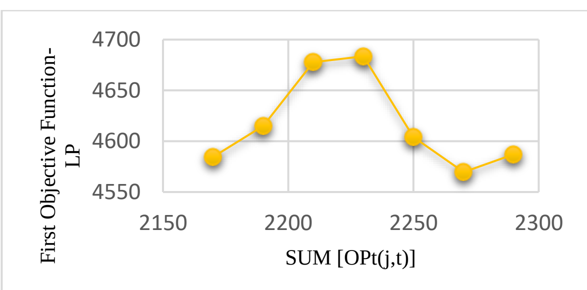


FIGURE 14
PRICE OF PRODUCTS SOLD BY THE TRADITIONAL RETAILERS AND THE FIRST OBJECTIVE FUNCTION

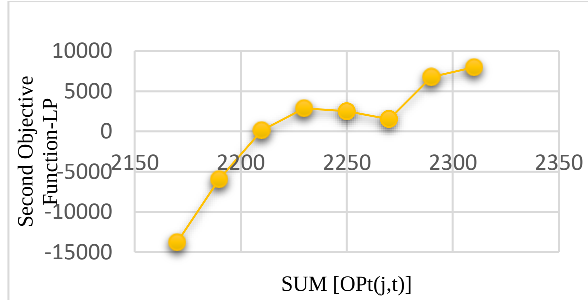
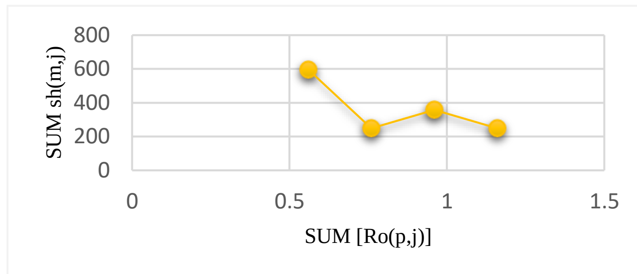


FIGURE 15
PRICE OF PRODUCTS SOLD BY THE TRADITIONAL RETAILERS AND THE SECOND OBJECTIVE FUNCTION

The price at which the products are sold is the main source of a chain to gain more benefit. So, with lower prices,



the benefit is lower or even negative which means that the company is in a loss. By increasing the prices, the benefit amount will be increased (Figure 15).

FIGURE 16
PERCENT OF DEFECTIVE PRODUCTS PRODUCED IN PLANTS AND SHORTAGE

Higher ρ_{pj} means more products to answer second markets' needs. So, obviously, there will be lower shortage quantity.ρ_{pj} is the most important parameter for second markets' demands. The increase in ρ_{pj} means we have more products to answer second markets' needs. So, there will be lower shortage quantity which will decrease shortage expenses (Figure 16).

Additionally, the distances in second market paths are shorter, because the price of defective products are lower than other products, so they provide lower benefit compared to normal products hence plants and retailer prefer to sell those products to customers around them to decrease the transportation costs. Additionally, people's loyalty to a plants' quality are one the most important factors which make loyal customers, therefore, if the defective products of a plant be sent to a vast area, it can hurt the brand of that plant which will have bad effects on its benefit and customers in the long term. That is why the second market customers are closer to the retailers (the distances are shorter) than other customers (Figure 17).

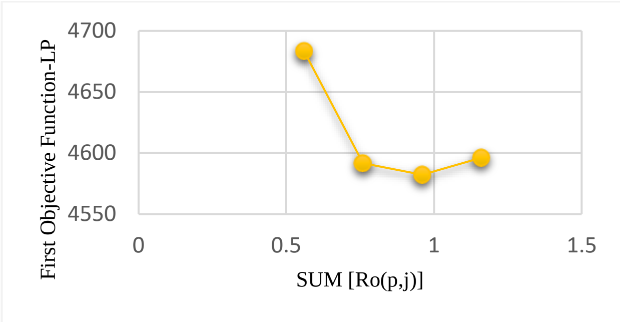


FIGURE 17
PERCENT OF DEFECTIVE PRODUCTS PRODUCED IN PLANTS AND THE FIRST OBJECTIVE FUNCTION

The increase in price increases the supply, because the companies want to gain more benefits by selling the products with higher prices, so more demand will be answered, which increases the benefit amount. After a while, more centers should be established to answer the demand, because the present centers will meet their capacity limitation, which at first increases the expenses and decreases the benefit. After a while, establishing new centers enables the companies to answer more demands which provides them with more benefits (**Error! Reference source not found.**).

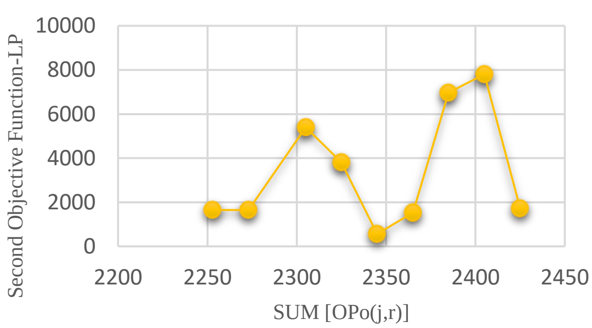


FIGURE 18
PRICE OF PRODUCTS SOLD BY THE ONLINE RETAILERS AND THE SECOND OBJECTIVE FUNCTION

Obviously, a company face shortage when the customers' demands exceed the company's supply. In the other hand, when a company increases its products' selling prices, some of the customers cannot afford that price, so the demand for that company's product will be decreased which will decrease the total demand of the company. This reduction in demand, reduces the shortage. The shortage reduction is low in the first steps, since the price of the products is not increased a lot, and lots of customers still can afford that, but by continuing increasing the price of the products, customers' demands for that product will be decreased, since they cannot afford its price, and finally the total demand will be reduced, which will result in shortage reduction.

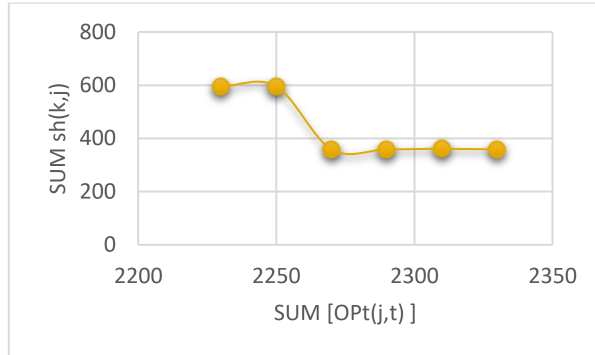


FIGURE19
PRICE OF PRODUCTS SOLD BY THE TRADITIONAL RETAILERS AND SHORTAGE AMOUNT.

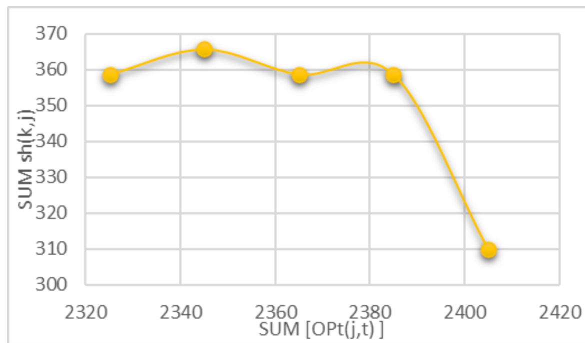


FIGURE 19
PRICE OF PRODUCTS SOLD BY THE ONLINE RETAILERS AND SHORTAGE AMOUNT

Based on Figure 20, by increasing the prices of online retailers, customers will be more inclined toward traditional retailers, so the demand for the traditional retailer will be increased, which will increase the sold products of traditional retailer. There are some points which show decrease in traditional retailers' sold products despite the increase in online retailers' prices. One reason can be that due to the high volume of demands of traditional retailer, that product got out of stock and customers were forced to buy from online retailers. Another possible reason can be that there are some products which are highly demanded in special periods (like jackets in winter) and traditional retailers did not have that product and again customers are forced to buy from online retailers.

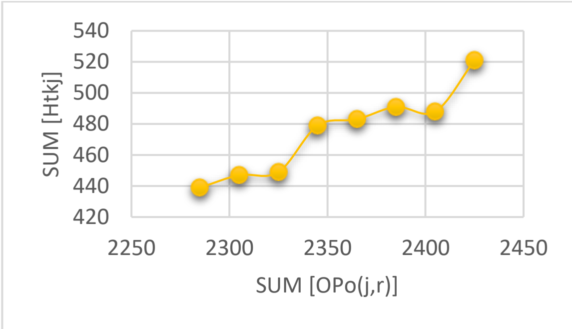


FIGURE 20
PRICE OF PRODUCTS SOLD BY THE ONLINE RETAILERS AND QUANTITY OF THE SOLD PRODUCTS BY TRADITIONAL RETAILER.

DISCUSSION

This research has some practical and marginal aspects. In most of the previous research, such as Aziziankohan et al. (2017), the green constraints were only applied to production plants. Nonetheless, many other parts of a supply chain produce GHG. In this regard, we applied these constraints to the production plants and transportation fleets for different parts of the supply chain in this paper. In order to do so, we introduced special parameters to represent the amount of GHG emission in the transportation of products between nodes per Km. On the other hand, we considered a separate objective function to minimize the total GHG emitted in the process of production and distribution while previous works, such as the one by Noh & Kim (2019), dedicated a specific cost to the GHG emission per ton and considered it as a part of cost objective function. The majority of the researches which are done on green closed-loop supply chain, like Guo et al., (2020), considered only a market center or a retailer in their forward echelon, but this paper went further and applied two types of retailers to the model: online and traditional. In this manner, the proposed model, similar to many recent studies, is much more related to actual situations and special conditions caused by the Covid-19 pandemic, which has driven parties to e-commerce (Heydari and Bakhshi, 2022). Moreover, unlike most of the previous researches, like Mohtashami et al., (2020), we considered the defects in products produced by our plants by dedicating a percent of total productions to defective products. A second market was then added to the model as a customer of defective products with lower prices than non-defective ones. As the second objective of this paper is to maximize the profit, unlike other researches that concentrated only on minimizing the cost, the results and sensitivity analysis can help managers with an insightful decisions tool to choose the most appropriate and profitable prices for their products. Additionally, facility location aspects in the model will help the managers to change the demand and other effective parameters of the problem to find the best places for locating plants, distribution, collecting, disposal, and repair centers.

Evaluating different aspects of the proposed model will provide lots of helpful information for managers to make better decisions. For example, figures 7 and 8 shows that the increase in demand increases the shortage amount and GHG emission, which will cause shortage costs, decreasing the benefit, and increasing environmental pollution, respectively. On the other hand, the increase in demand to a special amount increases the benefit. So, the managers can use the extra benefit they achieved to establish new production centers and buy modern facilities to decrease the shortage and GHG emission and gain more benefits. Figures 10 and 11 are showing a similar thing. By increasing the demand amount more than 750, both benefits and GHG emissions will be decreased since the managers use their extra benefits to buy new facilities and establish new centers to decrease shortage costs. Then when demands exceed 950, the benefit starts to increase again. Similar decisions can be made when the managers increase the prices. By increasing the selling prices of online and traditional retailers to 2230, the GHG emission and benefit amount started to decrease, showing that the managers used the extra money for facility investment and bought more environmentally friendly machines. These machines include production facilities and the machines used to transfer the products. The continuation of a price increase to 2270 will increase the benefit again, while the GHG emission is still decreasing, which shows that the extra benefit gained by a price increase, lower shortage, and lower environmental pollution will cover the expenses managers paid to buy the facilities and establish new centers. Additionally, the first objective function, which focuses on the minimization of GHG emissions, can be a helpful tool for managers to choose appropriate vehicles based on their priorities. Based on figures 15 and 18, considering online and traditional retailers and assessing the effects of changing their selling prices on companies' benefit is another advantage of using this model for managers. In other words, the proposed model is capable of helping managers decide how to allocate their products to different retailers to maximize their profit. In all production systems, defective products are inevitable. Most of the managers try to decrease the percent of defective products compared to the total production amount. Base on figure 16 and 17 and, as the proposed model has dedicated a percent of products to defective ones, managers can dedicate a desirable percent of products to the defective ones and assess the result of the model.

CONCLUSION AND FUTURE WORK

In this paper, a bi-objective NLP (Non-Linear Programming) model for green supply chain network design with reverse logistics consideration was proposed. Considering real-world conditions, four levels for forward flow and five levels for reverse flow were considered. The forward flow echelons include plants, distribution centers, online and traditional retailers, and customers. The reverse echelons include customers, collecting centers, disposal centers, and repair centers. All of the conditions for a reversed product from the customer, such as recycle, repair, and waste, are also investigated in this paper. Two objectives of this model are minimizing the GHG emission and maximizing the profit. One of the most important differences of this model compared to the others is that most of the papers dedicated a specific cost to GHG emission per Km and included it as a part of the cost objective function, however this model proposed a separate objective function to minimize the GHG emissions. Additionally, other papers only consider GHG emission of the production process. Nonetheless, this model considers all the GHG emitted in the production and transportation of a product. Unlike other studies that only minimize the costs, the second objective function of this paper maximizes the profit, which will enable the managers to find the price which matches their financial goals and is handleable for customers by changing the price of the products. In order to propose a model which is relatable to actual situations and challenges, a percent of the production was assigned to the defective products. In this regard, a separate group of customers are also defined as second market customers who buy defective products with lower prices than non-defective ones. Moreover, two different retailers, namely online and traditional were taken into account since the Covid-19 pandemic has derived the customers to do online shopping more than before. Finally, a sensitivity analysis on 4 important model parameters is done to check their effects on the objective functions to design an appropriate green closed-loop supply chain network.

As future work, some factors can be taken into account to further develop the proposed model in this paper. Firstly, uncertainty as a vital and inseparable factor of today's life can be applied to some parameters of the model such as demand of normal customers and also second market customers. Secondly, as the proposed model involves parameters related to cost and price, inflation can be of the essence in defining the quantity of the parameters such as price of the products and cost of establishing plants and centers over time. Thirdly, as an attempt to develop the model to be more compatible with real industry problems, failure for transportation vehicles can also be considered. Fourthly, as to have a more managerial contribution, supplier relationship management and supplier selection strategies are good fits to be considered while addressing the proposed problem and optimizing the proposed model. Lastly, forming queues of demand and customers in the distribution centers and retailers is not avoidable, hence considering the queueing-inventory models with defective products (Aghsami et al., 2021) in these sections would be more practical and exciting for future.

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SUPPLEMENTARY FILE

TABLE 1
PARAMETERS OF SOLVING THE PROBLEM IN SMALL SIZE WITH GAMS

Parameters	values	rameters	values	rameters	values	rameters	values
U^e	70000	Dm_{12}	14	SP_{21}^O	372	RE_{12}	26
A_{11}	30	Dm_{22}	13	SP_{11}^T	325	RE_{22}	24
A_{12}	30	Dm_{32}	11	SP_{21}^T	369	RE_{32}	20
A_{21}	36	Dm_{21}	4	SP_{12}^T	379	RE_{42}	23
A_{22}	42	Dm_{31}	12	SP_{22}^T	389	RE_{52}	10
A_{31}	39	Dm_{11}	9	REm_{11}	8	B_1^O	10000000
A_{32}	30	OP_{12}^T	535	REm_{21}	2	B_2^T	1080000
D_{11}	79	OP_{11}^T	560	REm_{31}	8	B_1^T	11000000
D_{21}	39	OP_{21}^T	580	REm_{12}	11	B_2^O	9700000
D_{31}	89	OP_{22}^T	595	REm_{22}	10	RE_{21}	30
D_{41}	89	OP_{11}^O	550	OP_{21}^O	580	RE_{31}	30
D_{51}	108	OP_{12}^O	540	OP_{22}^O	685	RE_{41}	29
D_{12}	111	D_{42}	100	SP_{12}^O	432	RE_{51}	22
D_{22}	79	D_{52}	76	SP_{22}^O	428	RE_{11}	40
D_{32}	80	SP_{11}^O	480	REm_{32}	8	π_{11}	20
D_{42}	100	ρ_{11}	0.15	ρ_{21}	0.13	π_{21}	23
D_{52}	76	ρ_{12}	0.15	ρ_{22}	0.13	π_{31}	25
π_{41}	30	π_{51}	33	π_{12}	21	π_{22}	25
FC_1^p	38800	FC_2^p	39100	FC_3^p	35100	FC_1^d	28000

TABLE 2
PARAMETERS OF SOLVING THE PROBLEM IN MEDIUM SIZE WITH GAMS

Parameters	values	Parameters	values	Parameters	values	Parameters	values	Parameters	values
U^e	70000	D_{41}	67	SP_{24}^T	272	RE_{21}	40	RE_{102}	25
A_{11}	33	D_{51}	77	SP_{13}^T	251	RE_{31}	39	REm_1	6
A_{12}	30	D_{61}	71	SP_{14}^T	247	RE_{41}	40	REm_2	9
A_{13}	35	D_{71}	74	SP_{23}^O	259	RE_{51}	35	REm_1	7
A_{14}	34	D_{81}	68	SP_{13}^O	270	RE_{61}	29	REm_2	2
A_{21}	36	D_{91}	70	SP_{22}^O	246	RE_{71}	27	REm_3	9
A_{22}	38	D_{101}	78	SP_{12}^O	245	RE_{81}	26	REm_3	5
A_{23}	35	D_{12}	78	Dm_{11}	15	RE_{91}	34	REm_4	7
A_{24}	36	D_{22}	72	Dm_{12}	14	RE_{101}	36	REm_4	4
A_{31}	39	D_{32}	66	Dm_{21}	12	RE_{12}	40	REm_5	2
OP_{13}^T	239	D_{42}	67	Dm_{22}	14	RE_{22}	26	REm_5	3
OP_{24}^T	282	D_{52}	77	Dm_{31}	9	RE_{32}	30	B_1^O	10000000
OP_{14}^T	282	D_{62}	71	Dm_{32}	10	RE_{42}	23	B_1^T	9900000
OP_{23}^T	291	D_{72}	65	Dm_{41}	13	RE_{52}	10	B_2^T	9500000
OP_{13}^O	228	D_{82}	65	Dm_{42}	12	RE_{62}	24	B_2^O	105000000
OP_{14}^O	274	D_{92}	71	Dm_{51}	14	RE_{72}	22	B_3^O	9900000
OP_{23}^O	205	D_{102}	76	Dm_{52}	12	RE_{82}	24	B_4^O	9950000
OP_{24}^O	288	SP_{23}^T	251	RE_{11}	40	RE_{92}	16	B_3^T	9490000
SP_{11}^O	233	π_{11}	35	π_{14}	35	π_{11}^m	29	π_{21}^m	25
SP_{14}^O	256	π_{12}	32	π_{21}	32	π_{12}^m	24	π_{31}^m	24
SP_{24}^O	254	π_{13}	31	π_{22}	37	π_{13}^m	21	π_{41}^m	21
FC_1^p	18000	FC_3^p	17100	FC_1^d	10000	FC_3^d	9800	FC_1^c	10000
FC_2^p	17100	FC_4^p	17900	FC_2^d	10000	FC_4^d	10500	FC_2^c	10100

TABLE 3
PARAMETERS OF SOLVING THE PROBLEM IN LARGE SIZE WITH GOA

Parameters	values	Parameters	values	Parameters	values	Parameters	values	Parameters	values
U^e	70000	D_{41}	106	SP_{24}^T	258	RE_{21}	45	RE_{102}	50
A_{11}	33	D_{51}	103	SP_{13}^T	264	RE_{31}	54	REm_{11}	7
A_{12}	30	D_{61}	108	SP_{14}^T	258	RE_{41}	56	REm_{21}	3
A_{13}	35	D_{71}	103	SP_{23}^O	243	RE_{51}	47	REm_{12}	3
A_{14}	34	D_{81}	109	SP_{13}^O	232	RE_{61}	51	REm_{22}	2
A_{15}	32	D_{91}	104	SP_{22}^O	248	RE_{71}	51	REm_{31}	2
A_{25}	34	D_{101}	108	SP_{12}^O	263	RE_{81}	45	REm_{32}	3
A_{35}	37	D_{12}	109	Dm_{11}	9	RE_{91}	52	REm_{41}	5
A_{55}	33	D_{22}	108	Dm_{12}	10	RE_{101}	57	REm_{42}	6
A_{31}	34	D_{32}	102	Dm_{21}	14	RE_{111}	51	B_5^T	9700000
OP_{15}^T	297	D_{42}	102	Dm_{22}	7	RE_{121}	45	B_5^O	10700000
OP_{25}^T	300	D_{52}	109	Dm_{31}	14	RE_{131}	56	B_1^O	10000000
OP_{35}^T	220	D_{62}	100	Dm_{32}	15	RE_{141}	45	B_1^T	9900000
OP_{45}^T	275	D_{72}	108	Dm_{41}	15	RE_{151}	54	B_2^T	9500000
OP_{15}^O	299	D_{82}	102	Dm_{42}	9	RE_{12}	50	B_2^O	105000000
OP_{25}^O	268	D_{92}	107	Dm_{52}	15	RE_{72}	58	B_3^O	9900000
OP_{35}^O	288	D_{102}	101	Dm_{65}	13	RE_{82}	50	B_4^O	9950000
OP_{45}^O	287	SP_{25}^T	203	RE_{11}	58	RE_{92}	50	B_3^T	9490000
ρ_{11}	0.65	ρ_{41}	0.48	π_{11}^m	29	π_{12}^m	22	π_{11}	35
ρ_{21}	0.27	ρ_{51}	0.46	π_{21}^m	26	π_{22}^m	24	π_{12}	40
ρ_{31}	0.31	ρ_{61}	0.19	π_{31}^m	29	π_{32}^m	27	π_{13}	33
FC_1^p	18000	FC_3^p	17100	FC_1^d	10000	FC_3^d	9800	FC_5^d	10700
FC_2^p	17100	FC_4^p	17900	FC_2^d	10000	FC_4^d	10500	FC_6^d	10100