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Research Article

Designing Sustainable Recovery Network of End-of-Life Product during the COVID-19 Pandemic: A Real and Applied Case Study

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One of the most important aspects of supply chain management (SCM) is the recovery network (RN), which covers all activities associated with return products (such as collection, recovery, repair, recycling, and waste disposal). Our goal in this paper is to provide a new mathematical model of sustainable end-of-life management (SEOLM) during the COVID-19 pandemic for readers. The suggested recovery network model (RNM) can explain the trade-offs between economic (minimizing total costs), environmental (minimizing bad environmental impacts), and social (minimizing bad social impacts) aspects during the pandemic and the great lockdown. A new RN can be designed with a sustainable and hygienic design when taking environmental, economic, and social considerations into account. It proposes guidelines for managers and scholars on how to address recovery network design (RND) challenges during the pandemic through a mathematical article with a sustainable approach. The scalarization approach of a multi-objective mixed-integer programming (MOMIP) problem in this paper is the weighted sum method. The validation of the presented model and the related Pareto frontier has been illustrated by a case study and numerical example. To perform the optimization process, Lingo software is used.

1. Introduction

COVID-19 can be contagious very quickly [1]. Keeping physical contact low and locking down are two important prevention strategies for COVID-19 [2]. Emissions are also fundamentally affected by the growing COVID-19 outbreak [3]. Resource consumption and environmental pollution can be reduced by recovering end-of-life (EOL) products [4, 5]. RN's total cost should be kept as low as possible [6]. The recovery technique is different on several factors: type of product, backward flow, the demand of the market, status of the product, and technical conditions. Maximization of the value of recovery of EOL products is important to make a recovery decision [7]. The important purpose of the disassembly method is to revitalize EOL products by methodically separating their parts and materials for recycling, reproduction, and reuse [8]. Most manufacturing companies focus on forwarding flows and pay no attention to the backward flows. The product life cycle (LC) consists of three steps. The last step is end of life (EOL): collecting/remanufacturing/reuse/recycle/disposal [9]. COVID-19 virus life spans on different surfaces are shown in Figure 1.

We need to consider how long the coronavirus remains on different objects. Product recovery minimizes waste by recovering, recycling, and reproducing [8]. Reducing CO_2 emissions is one of the important targets of RN design [18]. During the COVID-19 crisis and the intensive lockdowns, China's CO_2 emissions decreased [19]. Keeping a virus from infecting you is the best way to prevent illness [20]. Phuluwa et al. studied the implementation of EOL options for the railcar and development of a sustainable decision framework [21]. Based on the above assumption, this has to have the specifications of the EOL product. In the reverse logistics (RLs), the returned products are collected from customers

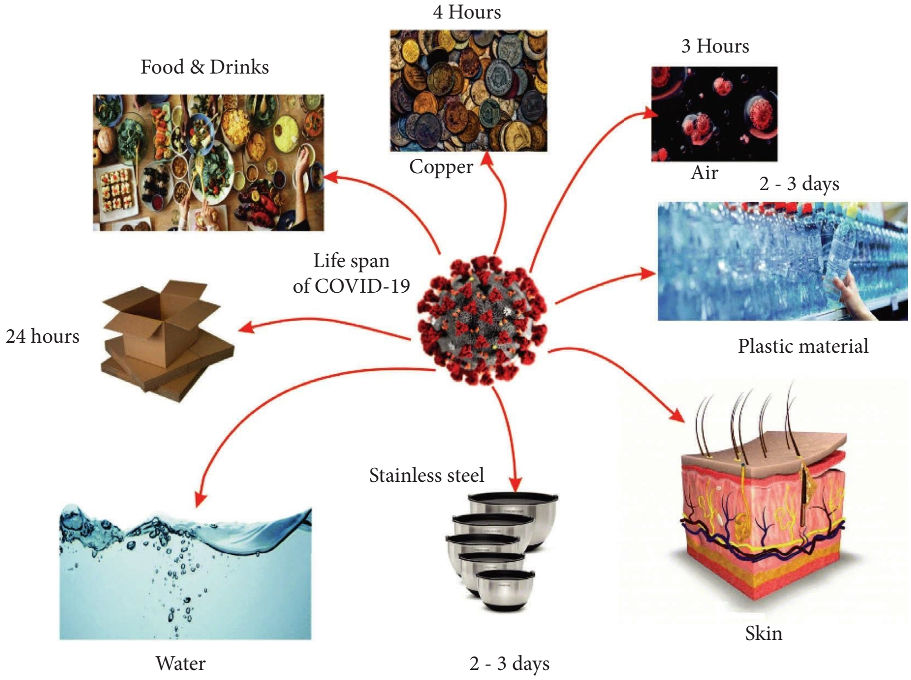

Figure 1: The life span of the COVID-19 virus on different surfaces [10–17].

and shipped to the collection centers, where the returned products are examined and classified as those that are suitable for remanufacturing/refurbishing, recovering/repairing, recycling, and the landfilling/incineration sent to the (F), (P), ($R = R_{\text{normal}}$ and $R_{\text{COVID-19}}$), and others sent to the disposal centers ($D = D_{\text{normal}}$and $D_{\text{COVID-19}}$). Quantity of the remanufacturing, refurbishing, recovering, repairing, and recycling products is consigned to the secondary market for new selling. The proposed recovery network model (RNM) can explain the trade-offs between economic, environmental, and social aspects during the pandemic and lockdown period. This paper simultaneously presents a sustainability framework's MOMIP model and COVID-19 pandemic issues.

2. Literature Review

2.1. Survey on the Related Investigation. Jun et al. [22] expressed a multi-objective optimization (MOO) for EOL product recovery. Zambrano-Monserrate et al. [23] presented multiple models for EOL management. Keivanpour et al. [24] suggested a closed-loop supply chain (CLSC) for EOL products. Ziout et al. [25] researched recovery techniques with various levels of data quality on EOL products. Remery et al. [26] solve the mathematical problem of EOL with a MIPM method. Xanthopoulos and Iakovou [27] classified EOL into six options. There are several types of research in RLs fields done by Minner [28, 29]. Bing et al. [30] designed the reverse flow of the waste of plastic with a sustainable approach. Rogetzer et al. [31] researched recycling materials with a sustainable approach. Two study sources provided a new way to predict the cost at the early stage for EOL products by specifying the best EOL option with the AHP method [32, 33]. Wilson and Goffnett [34] focus on RLs activities for EOL products considering the environment and societal issues. Gunji et al. [35] studied about optimization of the disassembly sequence for EOL products. Mamaghani and Boucher [36] investigated on recovery optimization of EOL products and considered reducing CO_2 emissions. Research on the disassembly of an EOL product considers CO_2 emission, cost of energy, and job creation [37]. Jain et al. worked on the EOL and waste management in the framework [17]. The collection method of EOL textiles and reverse logistics was studied by Gröhn [38]. Modoi and Mihai proposed the economy model between e-waste and end-of-life vehicles [39]. Hernandez-Betancur et al. [40] suggested a new approach for managing the EOL for the chemical industry. Zuidwijk and Krikke [41] focused on sustainable supply chain (SC) and RLs. Fathollahi-Fard et al. [42] investigated environmental and economic issues, designing a reverse flow for citrus fruit crates. Kaviyani-Charati et al. [43] researched SC considering environmental aspects with a mixed-integer linear programming approach. The analysis evaluated the intelligence component and greenness of Iranian ports using data envelopment analysis (DEA) by Sadri et al [44]. In a study by Daneshdoost et al. [45], they searched for a method based on hybrid meta-heuristic approaches for the minimization of cable production costs. Ghoushchi et al. [46] studied the landfill site selection problem. Fasihi et al. [47] researched RLs in the fish industry. Gautam et al. [48] investigated on circular economy approach for managing end-of-life photovoltaic e-waste in India. Rentizelas et al. [49] investigated circular economy pathways for reverse supply networks for wind turbine blades in Europe. Okumura et al. [50] proposed the model for evaluating the circularity of end-of-life products using reuse efficiency. Huang et al. [51] suggested a framework for materials flows by integrating circular economy principles and end-of-life management techniques.

Koroma et al. [52] researched on the future electricity mixes and different management strategies for end-of-life batteries while assessing the life cycle costs of battery electric vehicles. The sustainable recovery network (SRN) is considered in the following table. In Table 1, no papers have taken into address the multi-objective and COVID-19 pandemic issues simultaneously.

2.2. Research Gap and Innovation. Several research gaps exist due to the novelty of the COVID-19 pandemic. A summary of the paper can be categorized as follows: literature gaps, new assumptions, and innovations.

(1) Designing a mathematical model for production recovery considering the impacts of COVID-19 pandemic.
(2) Designing a hygienic RN during the COVID-19 outbreak.
(3) Establishing a new SRN based on sustainability in three dimensions:
   (i) Incorporating hygienic costs from COVID-19 into basic models to add economic aspects.
   (ii) Creating an assessment of the environmental benefits resulting from using recovered, remanufactured, and recycled EOL products during the COVID-19 and lockdowns.
   (iii) Developing the social dimensions of COVID-19 and lockdowns as they pertain to positive and negative consequences to society.
(4) Discussion of managerial implications to improve decision-making based on the model.

This study aims to fill this gap in the COVID-19 disaster condition by developing a new and hygienic SRN model.

3. Problem Statement and Assumptions

This research focuses on the SEOLM in RLs. This mathematical model has as its objective minimization of the COVID-19 and lockdown periods' costs, social effects, and environmental impacts on RN.

According to the mathematical model described above, seven types of facilities are available:

(1) Customers (C),
(2) Collection centers (M),
(3) Remanufacturing and refurbishing centers (F),
(4) Recovery and repair center (P),
(5) Normal and COVID-19 recycling centers (R),
(6) Normal and COVID-19 landfill and incineration centers (Disposal Centers) (D),
(7) Secondary markets (Reuse Market) (K).

Based on the above assumption, this has to have the specifications of the EOL product. In the RLs, the returned products are collected from customers and shipped to the collection centers, where the returned products are examined and classified as those that are suitable for remanufacturing/refurbishing, recovering/repairing, and recycling, sent to the (F), (P), ($R = R_{\text{normal}}$ and $R_{\text{COVID-19}}$), and others sent to the disposal centers ($D = D_{\text{normal}}$ and $D_{\text{COVID-19}}$) for landfilling and incineration. Three aspects of sustainability are discussed in this paper. Recycling reduces costs and improves economic efficiency while being environmentally friendly. This mathematical model combines economic, environmental, and social indicators in the RN during pandemics and lockdowns to increase efficiency. To create the RN, indices are used in a mathematical modeling method, and MOO is performed to complete the creation of the RN. The total cost is a measure to calculate all the monetary expenditure of the RN design. With the model, we can design RNs that best accommodate the following facilities (Customers-Collection Centers-Remanufacturing/Refurbishing Centers-Recovery/Repair Centers-Recycling Centers-Landfill/Incineration Centers-Secondary Markets) or we can distinguish product flows between the various levels. For the best network scenario, consider the total costs, the environmental and social factors related to RN activities during the COVID-19 and lockdown days. By having this information at their disposal, decision-makers (DMs) can make better, more sustainable decisions when faced with a pandemic. We describe the RND model in four subsections: problem statement and assumptions, model components, formulation process, and multiobjective mythology. The designed schematic of the problem is shown in Figure 2.

Mathematical models require several assumptions:

(1) It is supposed that a determined percentage of the returnedproducts are disposed.
(2) In the RN, the COVID-19 outbreak is thoroughly investigated.
(3) Potential areas include M, F, P, R, and D.
(4) Customers and secondary markets have fixed locations.
(5) Depending on the connection, there are different shipping options available.
(6) A feasible distance should be between network nodes.
(7) This study focuses on reverse flows.
(8) All returned product to be disposed that enters a disposal center is successfully incinerated and landfilled with hygiene protocols.
(9) Each recycling and disposal center is divided into normal and COVID-19 sections separately.
(10) All waste must be considered nonrecyclable and disposed of by incineration and sanitary landfill.
(11) Separate the infectious and noninfectious waste in the collection center.

3.1. Proposed Model. RN models include the following sets, parameters, and variables:

As the sets M, F, P, R, D, C, and K illustrate, they correspond to the potential collection centers, the potential

Table 1: Different aspects of the SRN consider the COVID-19 pandemic.

References	Considering economic aspects	Considering environmental aspects	Considering social aspects	Considering COVID-19 pandemic
[53]	*	*		
[54]	*	*		
[55]	*			
[56]	*			
[22]	*			
[57]	*			
[58]	*			
[59]	*			
[60]	*			
[61]	*	*		
[62]	*	*		
[63]	*	*		
[64]	*	*		
[65]	*			
[66, 67]	*	*		
[68]	*			
[69]	*	*	*	
[70]	*	*	*	
[47]	*			
[71]	*	*	*	
[34]	*	*	*	
[39]	*			
[40]	*	*	*	
This research	*	*	*	*

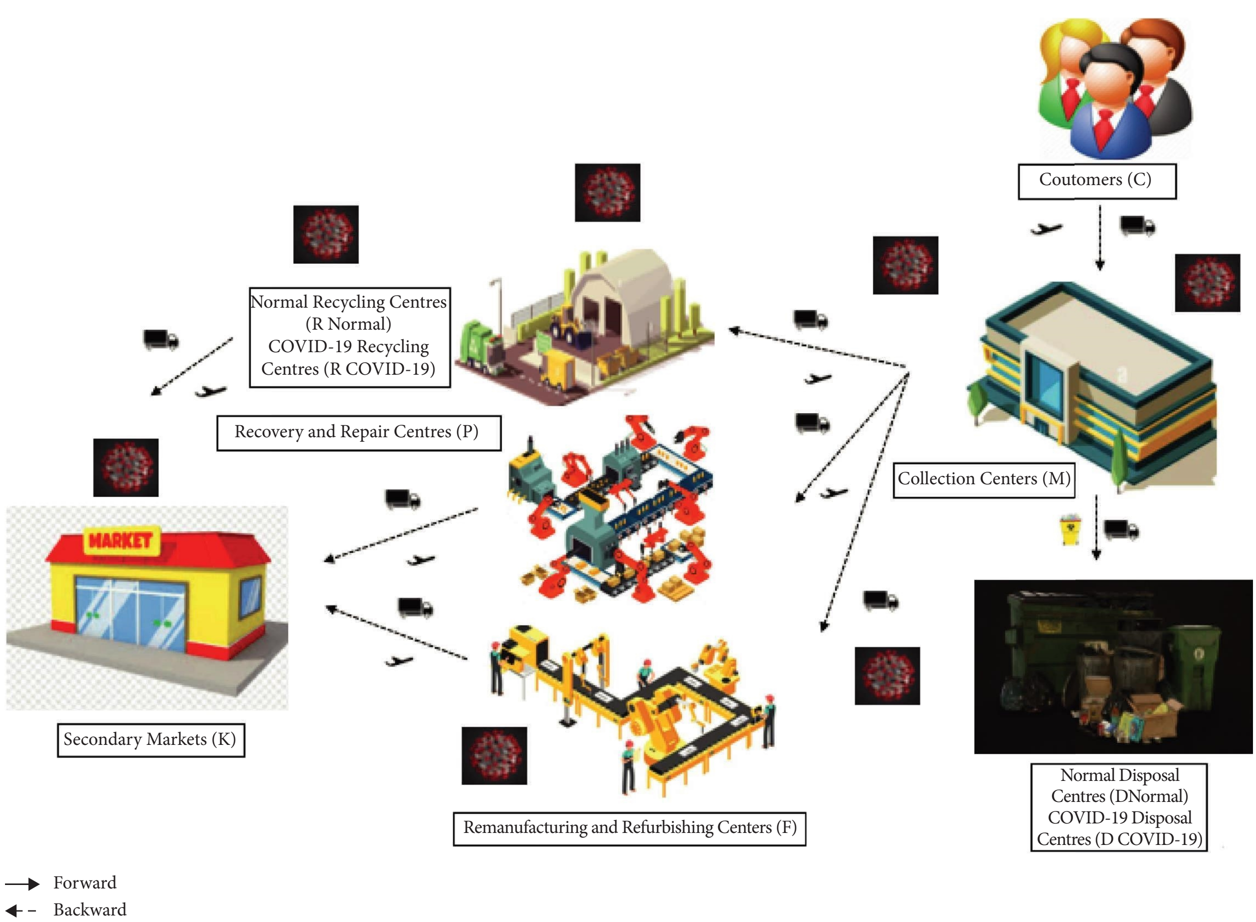

Figure 2: The RN between echelons during the COVID-19.

remanufacturing and refurbishing centers, the potential recovery and repair centers, the potential recycling centers, the potential disposal centers, the fixed customers, and the fixed secondary markets. The sets TC, TM, TF, TP, and TR include the shipping options from C, M, F, P, and R. The parameters of the model include technical, economic, environmental, and social parameters. In this model, the objective is to assign RNs to product units and determine the number of product units that flow through the network. The binary and decision variables help achieve this objective. The impacts of the COVID-19 virus on RN are shown in Figure 3 [10]. The new indicators of sustainability are shown in Table 2.

Notations:

The notations of the mathematic model were explained in this section.

Indices:

$c = \{1, 2, \ldots, C\}$: Set of fixed locations for customers.

$m = \{1, 2, \ldots, M\}$: Set of potential locations for collection centers.

$f = \{1, 2, \ldots, F\}$: Set of potential locations for remanufacturing and refurbishing centers.

$p = \{1, 2, \ldots, P\}$: Set of potential locations for recovery and repair centers.

$r = \{1, 2, \ldots, R\}$: Set of potential locations for recycling centers.

$d = \{1, 2, \ldots, D\}$: Set of potential locations for landfill and incineration centers (Disposal Centers).

$k = \{1, 2, \ldots, K\}$: Set of fixed locations for secondary markets (Reuse Market).

$tc = \{1, 2, \ldots, TC\}$: Set of shipping options from customers.

$tm = \{1, 2, \ldots, TM\}$: Set of shipping options from collection centers.

$tf = \{1, 2, \ldots, TF\}$: Set of shipping options from remanufacturing and refurbishing centers.

$tp = \{1, 2, \ldots, TP\}$: Set of shipping options from recovery and repair centers.

$tr = \{1, 2, \ldots, TR\}$: Set of shipping options from recycling centers.

Technical parameters:

Ω_c: The returned product of customer c.

CAP_m: Maximum capacity for collecting products.

CAP_f: Maximum capacity for remanufacturing and refurbishing products.

CAP_p: Maximum capacity for recovering and repairing products.

CAP_r: Maximum capacity for recycling.

CAP_d: Maximum capacity for landfilling and incinerating product.

δ_{cm}: Distance between customer c and collection center m.

δ_{mf}: Distance between collection center m and remanufacturing/refurbishing center f.

δ_{mp}: Distance between collection center m and recovery/repair center p.

δ_{mr}: Distance between collection center m and recycling center r.

δ_{md}: Distance between collection center m and disposal center d.

δ_{fk}: Distance between remanufacturing and refurbishing center f and secondary market k.

δ_{pk}: Distance between recovery/repair center p and secondary market k.

δ_{rk}: Distance between recycling center r and secondary market k.

Economic parameters:

F_m: Fixed cost for opening collection center m.

F_f: Fixed cost for opening remanufacturing/refurbishing center f.

F_p: Fixed cost for opening recovery/repairing center p.

F_r: Fixed cost for opening recycling center r.

F_d: Fixed cost for opening disposal center d.

C_m: The variable costs for collecting, inspecting, and sorting a unit of the returned and infectious/noninfectious waste in the collection center m.

C_f: The variable costs for remanufacturing and refurbishing a unit of returned product from the remanufacturing and refurbishing center f.

C_p: The variable costs for recovering and repairing a unit of returned product from the recovery/repairing center p.

C_r: The variable costs for recycling a unit of the returned product and infectious/noninfectious waste from the recycling center r.

C_d: The variable costs for landfilling and incinerating a unit of the returned product and infectious/noninfectious waste from the disposal center d.

TC_{cm}^{tc}: The unit shipping cost of the returned product and infectious/noninfectious waste sent from customer c to collection center m with shipping option tc.

TC_{mf}^{tm}: The unit shipping cost of the returned product is available for remanufacturing/refurbishing from collection center m to remanufacturing and refurbishing center f with shipping option tm.

TC_{mp}^{tm}: The unit shipping cost of the returned product is available for recovering and repairing from collection center m to recovery/repair center p with shipping option tm.

TC_{mr}^{tm}: The unit shipping cost of the returned product and infectious/noninfectious waste is available for recycling from collection center m to recycling center r with shipping option tm.

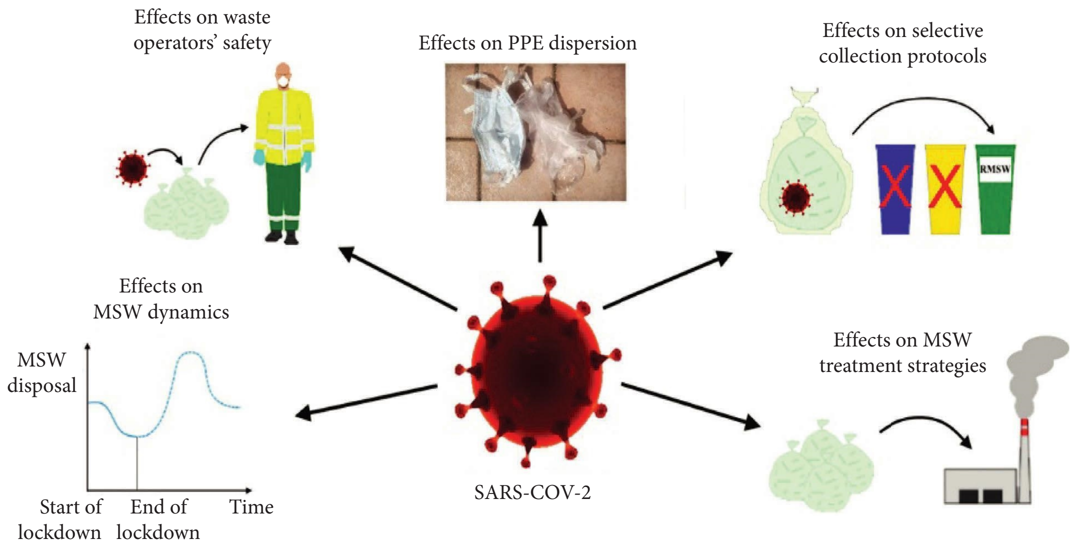

Figure 3: Effects of COVID-19 virus on RN.

Table 2: The indicators of sustainability for SRN during the COVID-19.

Indicator	Descriptions	Reference
Hygienic costs	Costs associated with preparing PPE for RN employees (shield, mask, gown, gloves, etc.). Costs associated with COVID-19 tests for RN employees. RN employees' education costs for preventing and controlling COVID-19. RN employees' medicines, vaccine, and vaccination costs. The cost of separating the infectious and noninfectious waste. The cost of disinfections and sanitizations in RN.	[72]
Positive effects of COVID-19 on environment	Reducing hazard gas emissions and recovery and industrial activities. Reducing hazard gas emissions and shipping activities. Minimizing noise pollution. Reduction of pressure on tourist destinations to restore the environment. Plant and animal species are protected. Development of IT parks, research centers, and consultancy related to COVID-19 prevention and control. Improved scientific and technological discoveries (medical advancement)	[55, 73–75]
Negative effects of COVID-19 on environment	Increase medical waste. Increasing the disposal of PPE waste (the pollution of soil and water caused by plastic waste). Growing infectious waste.	[23, 76, 77]
Positive effects of COVID-19 on social	Information on COVID-19 healthcare to the society. Several job opportunities are available in relation to COVID-19.	[78]
Negative effects of COVID-19 on social	The number of days lost as a result of damages caused by COVID-19. The number of employees affected by COVID-19.	[79]

TC_{md}^{tm}: The unit shipping cost of the returned product and infectious/noninfectious waste that is unsuitable for remanufacturing, refurbishing, repairing, and recycling, from collection center m to disposal center d with shipping option tm.

TC_{fk}^{tf}: The unit shipping cost of returned product from remanufacturing/refurbishing center f to secondary market k with shipping option tf.

TC_{pk}^{tp}: Unit shipping cost of returned product from recovery and repair center p to secondary market k with shipping option tp.

TC_{rk}^{tr}: Unit shipping cost of returned product from recycling center r to secondary market k with shipping option tr.

H_m: The unit cost of COVID-19 prevention and control for collecting, inspecting, and sorting a unit of the returned product and infectious/noninfectious waste in the collection center m.

H_f: The unit cost of COVID-19 prevention and control for remanufacturing and refurbishing a unit of the returned product in the remanufacturing/refurbishing center f.

H_p: The unit cost of COVID-19 prevention and control for recovering and repairing a unit of the returned product in recovery and repairing center p.

H_r: The unit cost of COVID-19 prevention and control for recycling a unit of the returned product and infectious/noninfectious waste in the recycling center r.

H_d: The unit cost of COVID-19 prevention and control for landfilling and incinerating a unit of the returned product and infectious/noninfectious waste in the disposal center d.

HTC_{cm}^{tc}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste from customer c to collection center m with shipping option tc.

HTC_{mf}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product is available for remanufacturing and refurbishing from collection center m to remanufacturing and refurbishing center f with shipping option tm.

HTC_{mp}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product is available for recovering/repairing from collection center m to recovery and repair center p with shipping option tm.

HTC_{mr}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste is available for recycling from collection center m to recycling center r with shipping option tm.

HTC_{md}^{tm}: The unit cost of COVID-19 prevention and control during the shipping of the returned product and infectious/noninfectious waste that is unsuitable for remanufacturing, refurbishing, repairing, and recycling from collection center m to disposal center d with shipping option tm.

HTC_{fk}^{tf}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from remanufacturing/refurbishing center f to secondary market k with shipping option tf.

HTC_{pk}^{tp}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from recovery and repair center p to secondary market k with shipping option tp.

HTC_{rk}^{tr}: The unit cost of COVID-19 prevention and control during the shipping of the returned product from recycling center r to secondary market k with shipping option tr.

Environmental parameters:

E_m: Environmental impacts for collecting one returned product and infectious/noninfectious waste in collection center m during the COVID-19.

E_f: Environmental impacts for remanufacturing and refurbishing one returned product in remanufacturing and refurbishing center f during the COVID-19.

E_p: Environmental impacts for recovering and repairing one returned product in the recovery/repair center p during the COVID-19.

E_r: Environmental impacts for recycling the one returned product and infectious/noninfectious waste in recycling center r during the COVID-19.

E_d: Environmental impacts for landfilling and incinerating one returned product and infectious/noninfectious waste in disposal center d during the COVID-19.

$\mathrm{ETC}_{\mathrm{cm}}^{\mathrm{tc}}$: Environmental impacts by shipping option tc to send a unit of rented product and infectious/noninfectious waste from customer c to collection center m during the COVID-19.

$\mathrm{ETC}_{\mathrm{mf}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product from collection center m to remanufacturing/refurbishing f for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{mp}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product from collection center m to recovery/repairing center p for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{mr}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of rented product and infectious/noninfectious waste from collection center m to recycling center r for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{md}}^{\mathrm{tm}}$: Environmental impacts by shipping option tm to send a unit of returned product and infectious/noninfectious waste from collection center m to disposal center d for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{fk}}^{\mathrm{tf}}$: Environmental impacts by shipping option tf to send a unit of rented product from remanufacturing/refurbishing f to secondary market k for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{pk}}^{\mathrm{tp}}$: Environmental impacts by shipping option tp to send a unit of rented product from recovering/repairing center p to secondary market k for a unit distance during the COVID-19.

$\mathrm{ETC}_{\mathrm{rk}}^{\mathrm{tr}}$: Environmental impacts by shipping option tr to send a unit of rented product from recycling center r to secondary market k for a unit distance during the COVID-19.

Social parameters:

LD_m: The average number of lost days caused by normal damages if a collection center m is open.

LD_f: The average number of lost days caused by normal damages if remanufacturing/refurbishing center f is opened.

LD_p: The average number of lost days caused by normal damages if a recovery/repairing center p is opened.

LD_r: The average number of lost days caused by normal damages if the recycling center r is opened.

LD_d: The average number of lost days caused by normal damages if disposal center d is opened.

LDC_m: The average number of lost days caused by COVID-19 damages if a collection center m is opened.

LDC_f: The average number of lost days caused by COVID-19 damages if remanufacturing and refurbishing center f is opened.

LDC_p: The average number of lost days caused by COVID-19 damages if a recovery/repairing center p is opened.

LDC_r: The average number of lost days caused by COVID-19 damages during the pandemic if the recycling center r is opened.

LDC_d: The average number of lost days caused by COVID-19 damages if disposal center d is opened.

JO_m: The number of created job opportunities if collection center m is opened.

JO_f: The number of created job opportunities if remanufacturing/refurbishing center f is opened.

JO_p: The number of created job opportunities if a recovery/repairing center p is opened.

JO_r: The number of created job opportunities if a recycling center r is opened.

JO_d: The number of created job opportunities if disposal center d is opened.

JOC_m: The number of created new job opportunities for the prevention and control of COVID-19 during collecting in the collection center m.

JOC_f: The number of created new job opportunities for the prevention and control of COVID-19 during remanufacturing and refurbishing in remanufacturing/refurbishing center f.

JOC_p: The number of created new job opportunities for the prevention and control of COVID-19 during recovering and repairing in recovery/repair center p.

JOC_{rm}: The number of created new job opportunities for the prevention and control of COVID-19 during recycling in recycling center r.

JOC_d: The number of created new job opportunities for the prevention and control of COVID-19 during landfilling and incinerating in disposal center d.

Variables:
Binary:

x_m: If collection center m is established, equal 1; otherwise 0.

x_f: If remanufacturing/refurbishing center f is established, equal 1; otherwise 0.

x_p: If recovery/repair center p is established, equal 1; otherwise 0.

x_r: If recycling center r is established, equal 1; otherwise 0.

x_d: If disposal center d is established, equal 1; otherwise 0.

Amount of returned product and waste:

Y_{cm}^{tc}: Quantity of units of returned product sent from customer c to collection center m with transportation tc.

Y_{mf}^{tm}: Quantity of units of returned product sent from collection center m to remanufacturing/refurbishing center f with transportation tm.

Y_{mp}^{tm}: Quantity of units of returned product sent from collection center m to recovery/repair center p with transportation tm.

Y_{mr}^{tm}: Quantity of units of returned product and waste sent from collection center m to recycling center r with transportation tm.

Y_{md}^{tm}: Quantity of units of returned product and waste sent from collection center m to disposal center d with transportation tm.

Y_{fk}^{tf}: Quantity of units of returned product sent from remanufacturing/refurbishing center f to secondary market k with transportation tf.

Y_{pk}^{tp}: Quantity of units of returned product sent from recovery/repair center p to secondary market k with transportation tp.

Y_{rk}^{tr}: Quantity of units of returned product sent from recycling center r to secondary market k with transportation tr.

3.2. Mathematical Model. The tri-objective design of the recovery network during the pandemic and lockdown periods is formulated as follows:

$$\begin{aligned} \text{Min } OF_1 &= \text{Total fixed cost (TFC)} + \text{Total variable cost (TVC)} \\ &\quad + \text{Total hygienic cost (THC)} + \text{Total transportation cost (TTC)}, \\ TFC &= \sum_m F_m x_m + \sum_f F_f x_f + \sum_p F_p x_p + \sum_r F_r x_r + \sum_d F_d x_d, \end{aligned} \tag{1}$$

$$TVC = \sum_m C_m \sum_c \sum_{tc} Y_{cm}^{tc} + \sum_f C_f \sum_m \sum_{tm} Y_{mf}^{tm} + \sum_p C_p \sum_m \sum_{tm} Y_{mp}^{tm} + \sum_r C_r \sum_m \sum_{tm} Y_{mr}^{tm} + \sum_d C_d \sum_m \sum_{tm} Y_{md}^{tm}, \tag{2}$$

$$\begin{aligned} THC &= \sum_{c}\sum_{m}\sum_{tc} TC_{cm}^{tc} Y_{cm}^{tc} + \sum_{m}\sum_{f}\sum_{tm} TC_{mf}^{tm} Y_{mf}^{tm} + \sum_{m}\sum_{p}\sum_{tm} TC_{mp}^{tm} Y_{mp}^{tm} + \sum_{m}\sum_{r}\sum_{tm} TC_{mr}^{tm} Y_{mr}^{tm} \\ &\quad + \sum_{m}\sum_{d}\sum_{tm} TC_{md}^{tm} Y_{md}^{tm} + \sum_{f}\sum_{k}\sum_{tf} TC_{fk}^{tf} Y_{fk}^{tf} + \sum_{p}\sum_{k}\sum_{tp} TC_{pk}^{tp} Y_{pk}^{tp} + \sum_{r}\sum_{k}\sum_{tr} TC_{rk}^{tr} Y_{rk}^{tr}, \\ TTC &= \sum_{m} H_m \sum_{c}\sum_{tc} Y_{cm}^{tc} + \sum_{f} H_f \sum_{m}\sum_{tm} Y_{mf}^{tm} + \sum_{p} H_p \sum_{m}\sum_{tm} Y_{mp}^{tm} + \sum_{r} H_r \sum_{m}\sum_{tm} Y_{mr}^{tm} + \sum_{d} H_d \sum_{m}\sum_{tm} Y_{md}^{tm} \\ &\quad + \sum_{c}\sum_{m}\sum_{tc} HTC_{cm}^{tc} Y_{cm}^{tc} + \sum_{m}\sum_{f}\sum_{tm} HTC_{mf}^{tm} Y_{mf}^{tm} + \sum_{m}\sum_{p}\sum_{tm} HTC_{mp}^{tm} Y_{mp}^{tm} + \sum_{m}\sum_{r}\sum_{tm} HTC_{mr}^{tm} Y_{mr}^{tm} \\ &\quad + \sum_{m}\sum_{d}\sum_{tm} HTC_{md}^{tm} Y_{md}^{tm} + \sum_{f}\sum_{k}\sum_{tf} HTC_{fk}^{tf} Y_{fk}^{tf} + \sum_{p}\sum_{k}\sum_{tp} HTC_{pk}^{tp} Y_{pk}^{tp} + \sum_{r}\sum_{k}\sum_{tr} HTC_{rk}^{tr} Y_{rk}^{tr}, \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Min OF}_2 &= \text{The total environmental impacts due to activities (EP)} \\ &\quad + \text{The total environmental impacts due to transportation (EH)}, \\ EP &= \sum_{m} E_m \sum_{c}\sum_{tc} Y_{cm}^{tc} + \sum_{f} E_f \sum_{m}\sum_{tm} Y_{mf}^{tm} + \sum_{p} E_p \sum_{m}\sum_{tm} Y_{mp}^{tm} + \sum_{r} E_r \sum_{m}\sum_{tm} Y_{mr}^{tm} + \sum_{d} E_d \sum_{m}\sum_{tm} Y_{md}^{tm} \\ &\quad + \sum_{f} E_f \sum_{k}\sum_{tf} Y_{fk}^{tf} + \sum_{p} E_p \sum_{k}\sum_{tp} Y_{pk}^{tp} + \sum_{r} E_r \sum_{k}\sum_{tr} Y_{rk}^{tr}, \end{aligned} \tag{4}$$

$$\begin{aligned} EH &= \sum_{c}\sum_{m}\sum_{tc} ETC_{cm}^{tc} Y_{cm}^{tc} \delta_{cm} + \sum_{m}\sum_{f}\sum_{tm} ETC_{mf}^{tm} Y_{mf}^{tm} \delta_{mf} + \sum_{m}\sum_{p}\sum_{tm} ETC_{mp}^{tm} Y_{mp}^{tm} \delta_{mp} + \sum_{m}\sum_{r}\sum_{tm} ETC_{mr}^{tm} Y_{mr}^{tm} \delta_{mr} \\ &\quad + \sum_{m}\sum_{d}\sum_{tm} ETC_{md}^{tm} Y_{md}^{tm} \delta_{md} + \sum_{f}\sum_{k}\sum_{tf} ETC_{fk}^{tf} Y_{fk}^{tf} \delta_{fk} + \sum_{p}\sum_{k}\sum_{tp} ETC_{pk}^{tp} Y_{pk}^{tp} \delta_{pk} + \sum_{r}\sum_{k}\sum_{tr} ETC_{rk}^{tr} Y_{rk}^{tr} \delta_{rk}, \end{aligned} \tag{5}$$

$$\begin{aligned} \text{Min } OF_3 = {} & \left[\left(LD_m x_m + LD_f x_f + LD_p x_p + LD_r x_r + LD_d x_d + LDC_m x_m + LDC_f x_f + LDC_P x_p LDC_r.x_r + LDC_d.x_d\right)\right] \\ & \left[\left(-JOm x_m + JOf x_f + JOp x_p + JOr x_r + JOd x_d + JOC_m.x_m + JOC_f.x_f + JOC_r.x_r + JOC_p.x_p + JOC_d.x_d\right)\right]. \end{aligned} \tag{6}$$

Subjected to:

$$\sum_{f}\sum_{tm} Y_{mf}^{tm} \le CAPm \, \forall m. \tag{7}$$

$$\sum_{p}\sum_{tm} Y_{mp}^{tm} \le CAPm \, \forall m, \tag{8}$$

$$\sum_{p}\sum_{tr} Y_{mr}^{tm} \le CAPm \, \forall m, \tag{9}$$

$$\sum_{d}\sum_{tm} Y_{m\,d}^{tm} \le CAPm \, \forall m, \tag{10}$$

$$\sum_{k}\sum_{tf} Y_{fk}^{tf} \le CAPf \, \forall f, \tag{11}$$

$$\sum_{k}\sum_{tp} Y_{pk}^{tp} \le CAPp \, \forall p, \tag{12}$$

$$\sum_{k}\sum_{tr} Y_{rk}^{tr} \le CAP\text{r} \, \forall r, \tag{13}$$

$$\sum_{k}\sum_{tf} Y_{fk}^{tf} \le \sum_{m}\sum_{tm} Y_{mf}^{tm} \, \forall f, \tag{14}$$

$$\sum_{k}\sum_{tp} Y_{pk}^{tp} \leq \sum_{m}\sum_{tm} Y_{mp}^{tm}\ \forall p, \tag{15}$$

$$\sum_{k}\sum_{tr} Y_{rk}^{tr} \leq \sum_{m}\sum_{tm} Y_{mr}^{tm}\forall r, \tag{16}$$

$$\sum_{d}\sum_{tm} Y_{m\,d}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{17}$$

$$\sum_{r}\sum_{tm} Y_{mr}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{18}$$

$$\sum_{p}\sum_{tm} Y_{mp}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\ \forall m, \tag{19}$$

$$\sum_{f}\sum_{tm} Y_{mf}^{tm} \leq \sum_{m}\sum_{tc} Y_{cm}^{tc}\forall m, \tag{20}$$

$$\sum_{m}\sum_{tc} Y_{cm}^{tc} \leq \Omega_c\ \forall c, \tag{21}$$

$$Y_{cm}^{tc}.Y_{mf}^{tm}.Y_{mp}^{tm}.Y_{mr}^{tm}.Y_{m\,d}^{tm}.Y_{pk}^{tp}.Y_{rk}^{tr}.Y_{fk}^{tf} \geq 0\ \forall m.\forall f.\forall p.\forall r.\forall d.\forall c, \tag{22}$$

$$X_m.X_f.X_r.X_p.X_d\{0.1\}\ \forall m.\forall f.\forall r.\forall p.\forall d. \tag{23}$$

The OFs: The mathematical formulations of the OFs are described in equations (1)–(6). The total cost is the summation of the fixed costs, the variable cost, the total shipping cost, and the total hygienic cost. The total impacts of COVID-19 on the environment are calculated by consideration of the negative and positive due to collecting, remanufacturing, refurbishing, recovering, repairing, recycling, disposing, and shipping during the COVID-19 and lockdowns. The total bad social impact is calculated by subtracting the number of lost days and created job opportunities throughout RN during the COVID-19.

The constraints of the model are shown in equations (7)–(23).

Constraint (7) states the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any remanufacturing and refurbishing centers via any shipping options must be less than or equal to the collection center's capacity. Constraint (8) shows the total number of returned product units shipped from a collection center to any recovery and repair center via any shipping options must be less than or equal to the collection center's capacity. Constraint (9) presents the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any recycling center via any shipping options must be less than or equal to the collection center's capacity. Constraint (10) describes the total number of the returned product and infectious/noninfectious waste units shipped from a collection center to any disposal center via any shipping options must be less than or equal to the collection center's capacity. Constraint (11) explains the total number of returned product units shipped from a remanufacturing and refurbishing center to any secondary markets via any shipping options must be less than or equal to the remanufacturing and refurbishing center's capacity. Constraint (12) illustrates the total number of returned product units shipped from a recovery and repair center to any secondary markets via any shipping options must be less than or equal to the recovery and repair center's capacity. Constraint (13) shows the total number of the returned product and infectious/noninfectious waste units shipped from the recycling center to any secondary markets via any shipping options must be less than or equal to the recycling center capacity. Constraint (14) describes the total number of returned product units shipped from a remanufacturing and refurbishing center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any remanufacturing and refurbishing centers. Constraint (15) states the total number of returned product units shipped from the recycling center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any recycling center. Constraint (16) shows the total number of returned product units shipped from a recovery and repair center to any secondary markets via any shipping options must be less than or equal to the total number of returned product units shipped from collection centers to any recovery and repair center. Constraint (17) describes the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any disposal center. Constraint (18) states the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any recycling center. Constraint (19) shows the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any recovery and repair center. Constraint (20) describes the total number of returned product units shipped from the customers to any collection centers via any shipping options must be greater than or equal to the total number of returned product units shipped from collection centers to any remanufacturing and refurbishing center. Constraint (21) explains the total quantity of units of the returned product collected from a customer to any collection centers through any shipping options should be lower than the respective customer's returned product. Constraint (22) narrates the total number of the returned product and infectious/noninfectious waste flowed from a customer c to a collection center m via a shipping method, a collection center m to a remanufacturing/refurbishing center f via a shipping method, a collection center m to a recovery and repair center p via a shipping method, a collection center m to a recycling center via a shipping mode, and a collection center m to a disposal center via a shipping mode. The number of the returned products for remanufacturing, refurbishing, recovering and repairing, or recycling from F, P, R to secondary market(s) are equal or greater than zero. Constraint (23) describes binary number for the potential of facilities (M, F, P, R, and D).

3.3. Solution Approach. In multi-objective optimization problems (MOOPs), two or more objective functions are minimized or maximized. The Pareto-optimal set (POS) consists of the nondominant set of entirely possible decision spaces. The Pareto-optimal front (POF) is the bounder specified by the POS for a collection of points.

3.3.1. Weighted Sum Method. Scalarization is the traditional method of solving MOOP, which involves formulating a single-objective optimization problem (SOOP) associated with the MOOP [80].

$$\begin{aligned} &\min\left(f_1(x), \ldots, f_p(x)\right). \\ &\text{subjec to: } x \in X. \end{aligned} \tag{24}$$

The weighted sum method (WSM) uses the vector of weights $\lambda \in R^p \geq$ as a parameter [80].

$$\begin{aligned} &\min \sum_{k=1}^{p} \lambda_k f_k(x), \\ &\text{subjec to: } x \in X. \end{aligned} \tag{25}$$

To manage the WSM, each aspect must be weighed and the weighted sum must be minimized. Solving MOP with the SO approach is the excellence of this method [81].

Three OFs can be solved with WSM:

$$\text{Minimize}\, w_1 f_1 + w_2 f_2 + w_3 f_3. \tag{26}$$

Subject to equations (7)–(23), where $w_1 \geq 0$, $w_2 \geq 0$, and $w_3 \geq 0$ are weights such that $w_1 + w_2 + w_3 = 1$; and f_1, f_2, and f_3 the OFs. For a better understanding of the Pareto concept, we present Figure 4 [80–82].

3.3.2. Pareto Frontier. The solution method is described in this section. The nondominant solutions to MOOP are well known. We call them Pareto-optimal solutions. This paper aims to provide an evenly distributed Pareto solution via a frontier from Pareto. This makes it easier for DMs to choose the right configuration. By demonstrating that the design space is well represented in the Pareto set, a Pareto distribution solution makes it easier for decision-makers to make a decision. The MO model has three OFs, and the objective value of these three functions is illustrated by f_1, f_2, and f_3, respectively. Once the model has been solved with each OF separately, we can obtain the objective values f_1^*, f_2^*, and f_3^* corresponding to objectives one, two, and three, respectively. In the end, the Pareto set was generated. For the Pareto-optimal set and the solution of the model, we will use the MOMIP solver Lingo. An example numerical example and case study are then used to test the model.

4. Numerical Examples and Case Study

A numerical example and case study are created to demonstrate and analyze the model performance. The reverse network in the proposed numerical example comprises seven facilities: customers, collection centers, remanufacturing/refurbishing centers, recovery/repair centers, recycling centers, and disposal centers. Potential locations of RN facilities (M, F, P, R, and D) and existing C and K are given, shipping options from customers, collection centers, remanufacturing/refurbishing centers, recovery/repair centers, and recycling centers (TC, TM, TF, TP, and TR). Table 3 provides information about facilities and transportation. Suppose we focus on economic, environmental, and social impact during the COVID-19 pandemic, in that case, the total environmental effect is calculated by adding the total impacts due to collecting returned production and infectious/noninfectious waste, remanufacturing, refurbishing, recovering, repairing, recycling, landfilling, incinerating, and the total impacts due to shipping. It has been assumed all activities in this model are observance of hygiene protocol during the COVID-19 pandemic and lockdowns. The problem in the small dimension is depicted in Figure 5.

The Pareto frontier of the numerical example and the case study is illustrated in Figures 6–9.

4.1. Sensitivity Analysis of Optimization Value (Base Scenario). A sensitivity analysis is performed to investigate the effects of model parameters. The optimization of the solutions was analyzed about changes in the conditions of the problem. In two different scenarios, we compare the economic, environmental, and social objective functions.

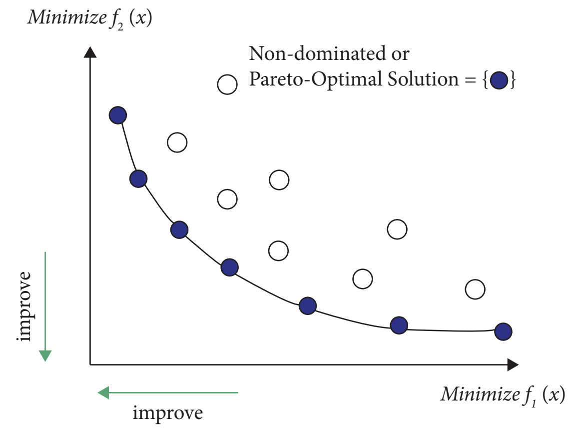

FIGURE 4: Graphic depiction of the Pareto solutions.

TABLE 3: Number of facilities and transportation mode.

Indices	Values
C	{1, 2, 3, . . ., 5}
M	{1, 2, 3, . . ., 7}
F	{1, 2, 3, . . ., 5}
P	{1, 2, 3, . . ., 6}
R	{1, 2, 3, 4}
D	{1, 2, 3, 4}
K	{1, 2, 3}
TC	{1, 2, 3, 4}
TM	{1, 2, . . ., 6}
TF	{1, 2}
TP	{1, 2, 3}
TR	{1}

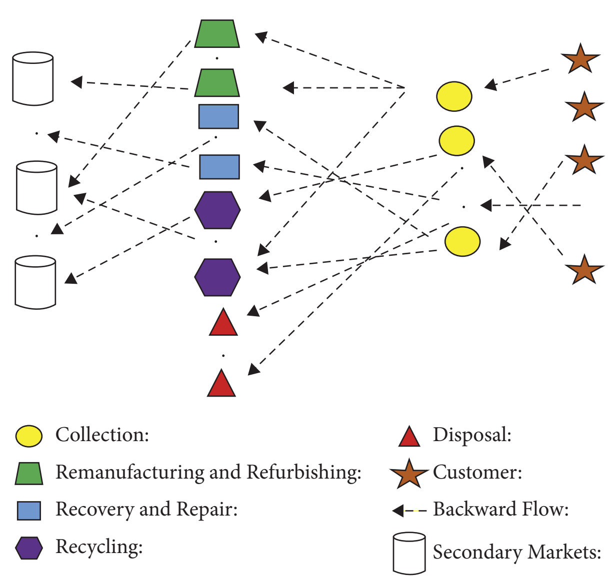

FIGURE 5: Locations of RN facilities in small dimension.

Under different scenarios, such as fallow, the economic, environmental, and social objectives are valued differently. The optimization value of the economics, environmental, and social aspects with normal and COVID-19 conditions is analyzed in Tables 4–6.

The findings of the proposed network demonstrated that the RN has become environmentally sustainable. Under the COVID-19 scenario, the environment objective function optimization value is better than under the normal scenario (Figure10). With the normal scenario, the economic objective function optimizes better than with COVID-19 (Figure 11). Under the normal scenario, the social objective function optimizes better than in the COVID-19 situation scenario (Figure 12).

4.2. Sensitivity Analysis of Dimensions of the Problem. Several numerical examples in different dimensions (small, medium, large) are used to examine the performance of SRN. 15 numerical examples are provided in this regard. Information about the dimensions of the problems is shown in Table 7, and the results of solving are presented in Table 8. By considering this matter, we have done a sensitivity analysis. The number of shipping options is fixed, and it is one during the recovery network ($|tc| = |tm| = |tf| = |tp| = |tr| = 1$).

As the dimensions of the problem increase, the OF's value increases. By increasing the dimensions of a problem, the optimal value of each OF increases. According to Figures 13–15, these increases do not follow a linear pattern, and the rate of rising varies from case to case. The proposed model can find the optimal solution in varying conditions and situations, as demonstrated by several examples of small, medium, and large dimensions

5. Managerial Implications and Practical Insights

In this study, the RND was designed for the COVID-19 outbreak. As a result of this research, useful policies for disaster management will be produced, especially if COVID-19 conditions are observed, and the relevant managers will be able to do the following: (i) management of the RN should have considered the hygienic costs associated with their RN. (ii) Employees should be able to be replaced when disasters arise. (iii) Managers have a responsibility to inform employees about COVID-19's negative consequences. (iv)

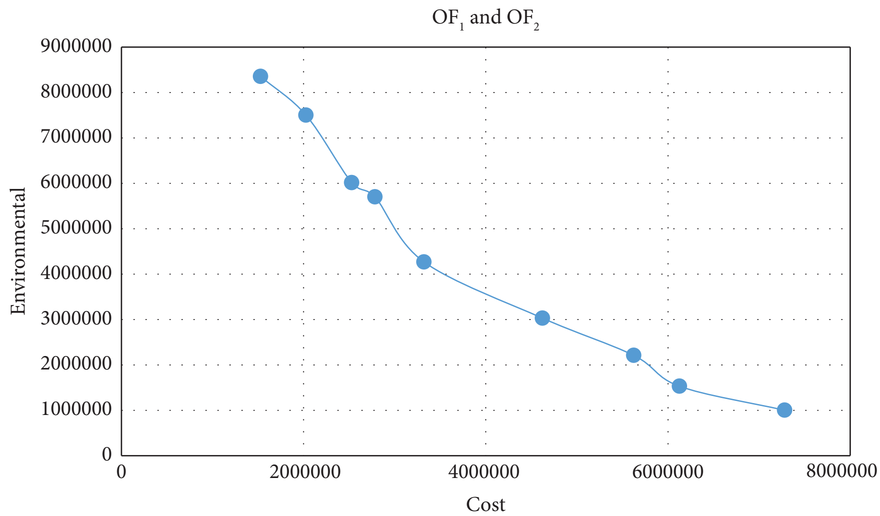

Figure 6: Pareto frontier of the numerical example.

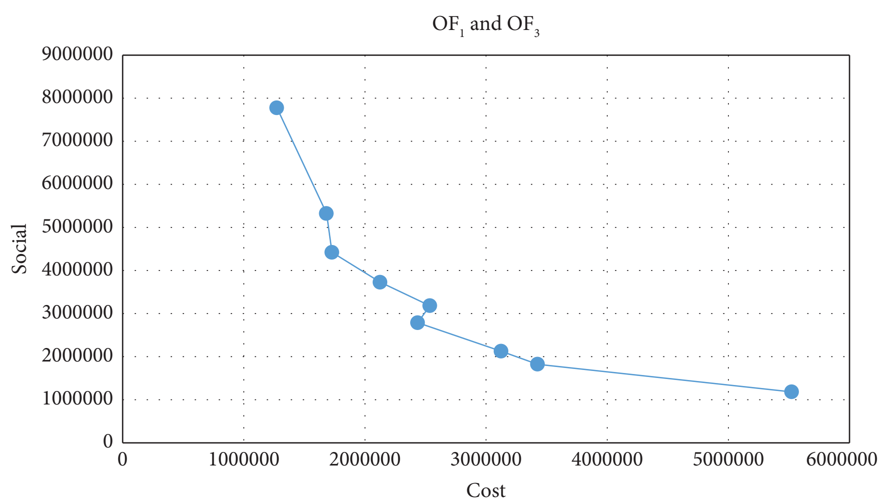

Figure 7: Pareto frontier of the numerical example.

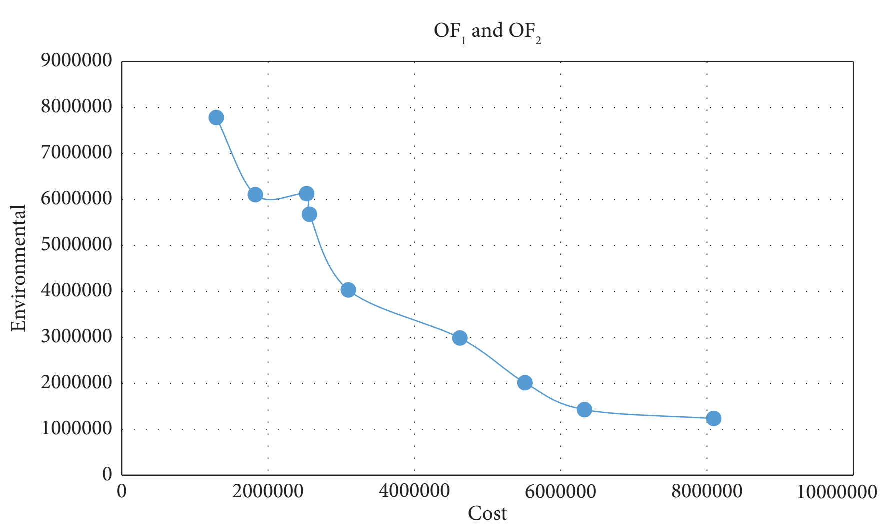

Figure 8: Pareto frontier of the case study.

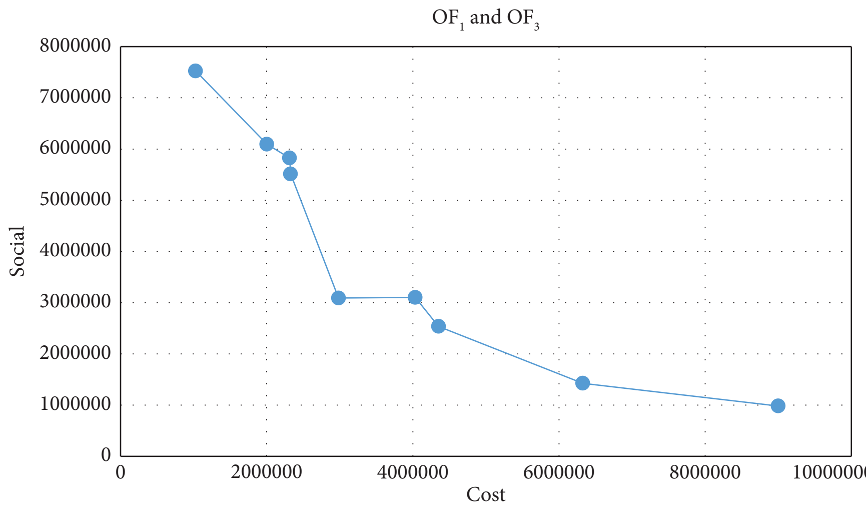

Figure 9: Pareto frontier of the case study.

Table 4: The optimization value of the economics OF with different scenarios.

Number	(Normal condition) considering model with hygienic cost	Number	(COVID-19 condition) considering model without hygienic cost
Situation 1	(i) Normal fixed costs (ii) Normal variable costs (iii) Shipping costs (iv) Z^* normal = 5527638	Situation 2	(i) Fixed costs (ii) Variable costs (iii) Shipping costs (iv) Hygienic costs (v) Z^* COVID-19 = 6010112

Table 5: The optimization value of the environmental OF with different scenarios.

Number	(Normal condition) total environmental impact without concerning COVID-19	Number	(COVID-19 condition) total environmental impact concerning COVID-19
Situation 1	(i) Normal plastic waste. (ii) Normal soil pollution. (iii) Normal gas emissions of industrial activities. (iv) Normal gas emissions of shipping activities. (v) Normal water consumption and pollution due to noninfectious waste (vi) Z^* normal = 2786549	Situation 2	(i) Plastic and PPE waste during the COVID-19 pandemic. (ii) Soil pollution during the COVID-19 pandemic. (iii) Gas emissions of industrial activities during the COVID-19 pandemic and lockdown periods. (iv) Gas emissions of shipping activities during the COVID-19 pandemic and lockdown periods. (v) Water consumption and pollution during the COVID-19 pandemic. (vi) Infectious waste. (vii) Z^* COVID-19 = 1987652

Table 6: The optimization value of the social OF with different scenarios.

Number	Normal condition model total social impact without concerning COVID-19	Number	COVID-19 condition model total social impact concerning COVID-19
Scenario 1	(i) Customers' service satisfaction. (ii) The average number of lost days caused by normal damages (iii) The number of created normal job opportunities. (iv) Z^* normal = 8109287	Scenario 2	(i) Customers' service satisfaction in a disaster situation. (ii) The average number of lost days caused by COVID-19 damages (iii) The number of created new job opportunities to prevent and control COVID-19. (iv) Z^* COVID-19 = 9087321

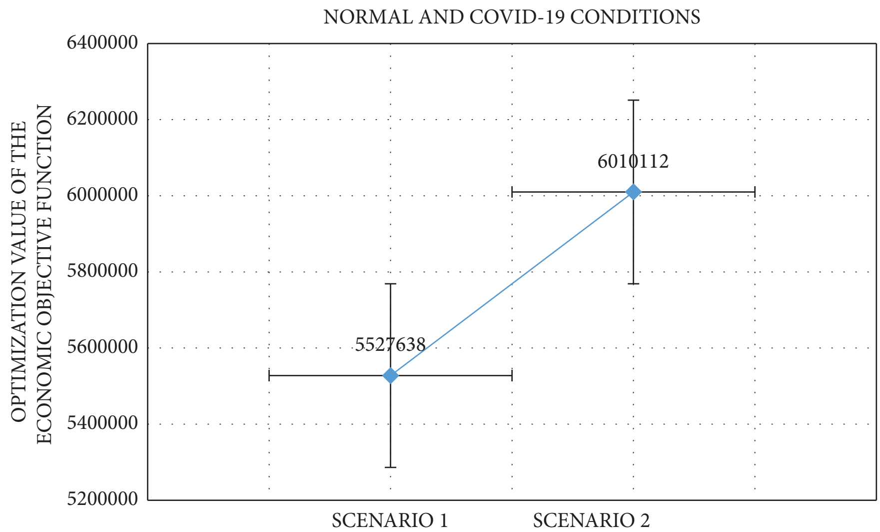

Figure 10: Sensitivity analysis of economic aspect (normal COVID) models.

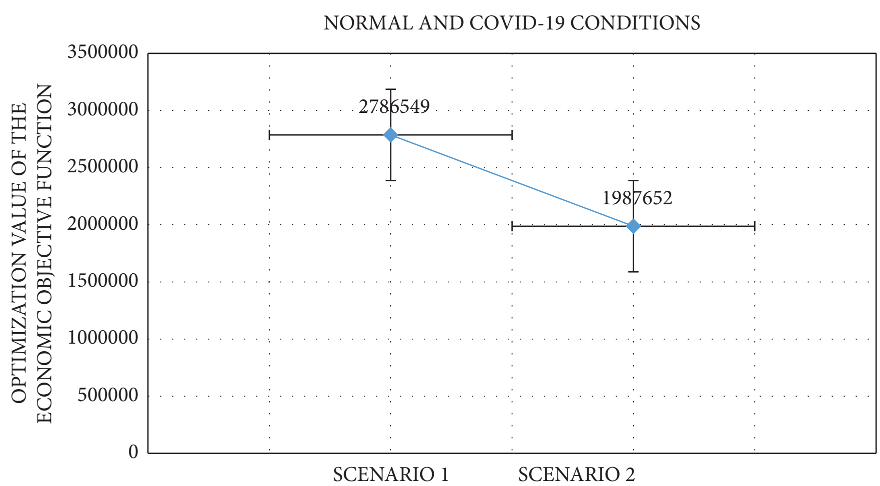

Figure 11: Sensitivity analysis of environmental aspect (normal COVID) models.

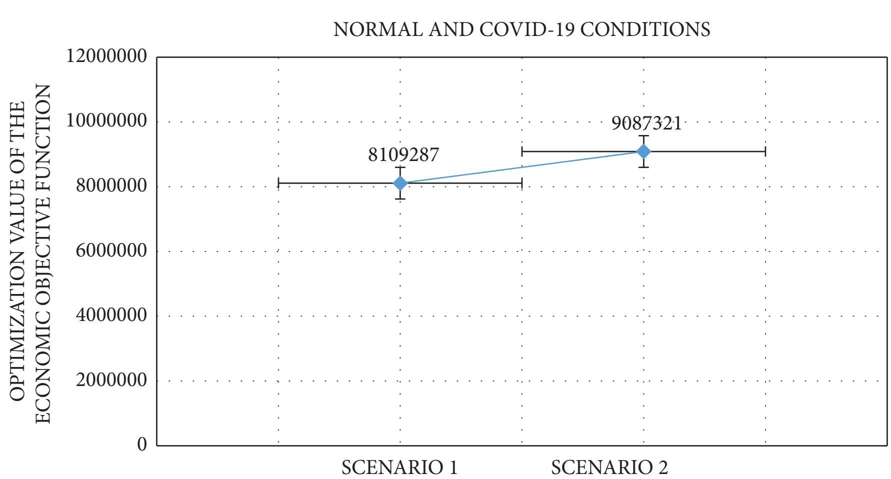

Figure 12: Sensitivity analysis of social aspect (normal COVID) models.

Table 7: Dimensions of design numerical examples.

Dimensions	Name	$\lvert C\rvert$	$\lvert M\rvert$	$\lvert F\rvert$	$\lvert P\rvert$	$\lvert R\rvert$	$\lvert D\rvert$	$\lvert K\rvert$
Small	P1	4	2	1	2	2	1	3
	P2	5	3	2	2	3	3	4
	P3	6	3	2	3	4	3	4
	P4	8	4	3	3	4	4	5
	P5	9	5	4	5	5	6	7
Medium	P6	10	8	5	6	6	7	8
	P7	13	7	5	7	6	8	8
	P8	15	7	5	7	6	10	11
	P9	17	8	6	8	8	11	13
	P10	20	8	6	10	9	12	15
Large	P11	22	9	7	12	10	14	18
	P12	23	9	9	13	11	16	20
	P13	25	10	11	13	12	16	21
	P14	30	11	15	14	13	18	26
	P15	40	11	15	14	16	20	30

Table 8: Results of solving.

Name	Optimal economic value	Optimal environmental value	Optimal social value	Solution time (seconds)
P1	320011.5	520412.2	2300.007	0.13
P2	330011.5	728314.0	2500.119	0.14
P3	340011.5	827510.7	2784.157	0.16
P4	370010.8	958620.1	3009.100	0.16
P5	390012.9	1038509.9	3004.280	0.17
P6	403486.5	1028509.0	3164.000	0.19
P7	501435.6	10290807.8	3260.000	0.22
P8	511123.5	1128509.1	3252.000	0.22
P9	598003.9	1210045.9	4820.000	0.25
P10	623191.9	1319945.4	5312.000	0.27
P11	822251.9	1411145.0	5648.000	0.27
P12	929260.5	1612345.0	5500.990	0.27
P13	1087650.8	1912345.0	5809.990	0.29
P14	1153370.5	2028615.0	6207.120	0.31
P15	1291010.3	2023231.0	6607.000	0.33

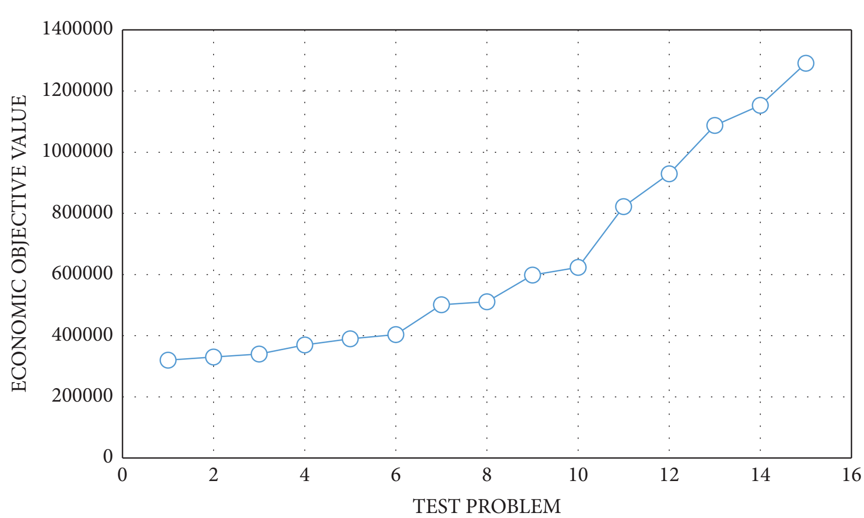

Figure 13: The value of the economics OF with different scenarios.

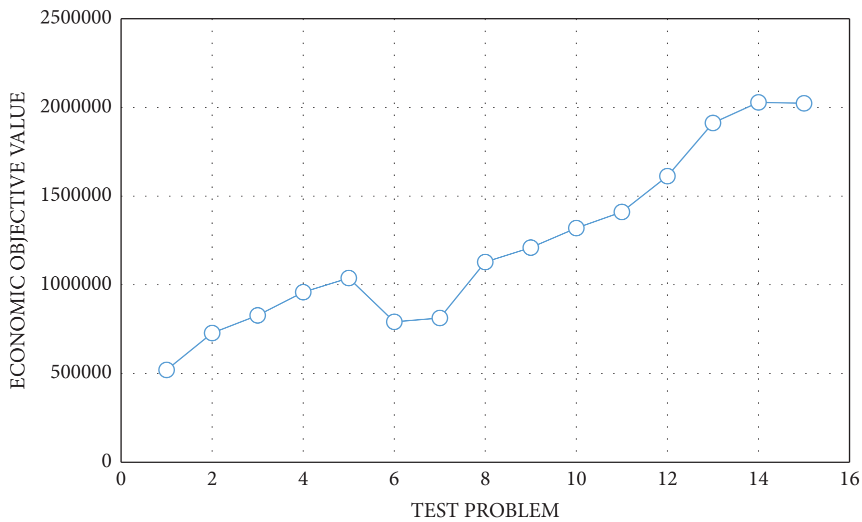

Figure 14: The value of the environmental OF with different scenarios.

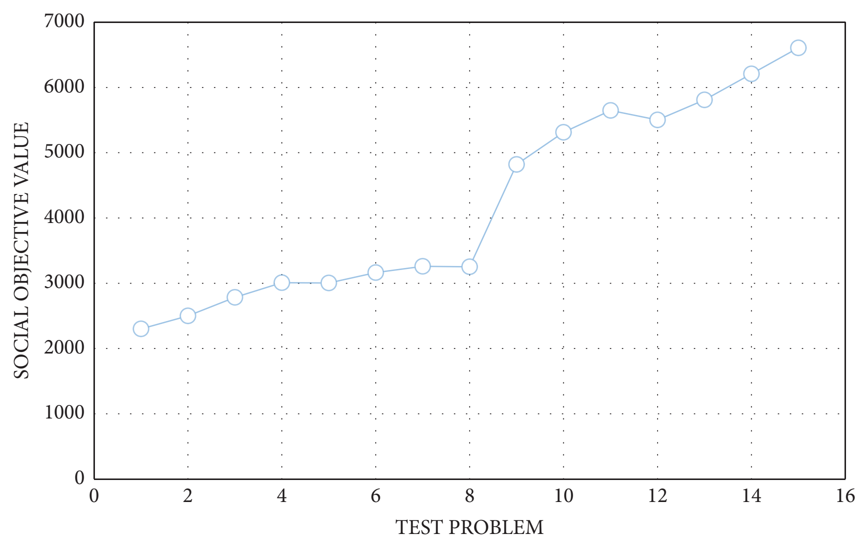

Figure 15: The value of the social OF with different scenarios.

During the collection of hazardous waste, managers should consider the health of workers. Finally, this study provides insight into how the RN can manage during the COVID-19 pandemic.

6. Conclusion, Limitations, and Future Works

During the COVID-19 disaster, this paper examined urgent global issues concerning returned products and waste management. RNs are impacted by COVID-19, and it is an exceptionally rare and extraordinary event. This study proposed the model for sustainable end-of-life management (SEOLM) during the COVID-19 pandemic. First, a review of previous related studies was conducted. Subsequently, a sustainable recovery network (SRN) was developed, based on the latest research items. The model consists of customers, collection centers, remanufacturing and refurbishing centers, recovery and repair centers, recycling centers (normal/COVID-19), landfills and incineration (Disposal) centers (normal/COVID-19), and secondary markets (Reuse markets). A MOMIP problem model has been proposed for SRN during COVID-19 and lockdown periods. The suggested mathematical model is formulated by considering the multidimensional aspects of sustainability, minimizing costs, minimizing bad environmental effects, and minimizing bad social effects. For the scalarization approach, we use the WSM. This process was optimized by using Lingo software. An example case study and numerical example were used to illustrate the validation of the presented model, along with a diagram of the Pareto front. A model such as this is sensitive to cost structure, so the model includes both normal costs and COVID-19 costs. Among the main findings of our paper were as follows: proposed a new model for SRN to demonstrate better the trade-offs between various aspects of sustainability in pandemics and lockdowns, (ii) designing the hygiene and safe workplace for the employees and employers in RN (especially hazard waste), (ii) developing indicators of the social, environmental, and economic dimensions, and (iv) RN has experienced both negative and positive effects of COVID-19 and lockdowns.

Our study has several limitations that need to be addressed in future research:

(i) Only one real company provided us with data.

(ii) Due to the lack of accurate information, some of the data was estimated.

(iii) The model is a single product and single-period network designed.

(iv) Lack of scientific resources and available statistics and information: In this regard, some problems have made research services such as access to books, journals, statistics, and databases in the country not easily possible.

(v) Limited budget required to do and advance the work: Each research work in its various stages requires spending financial costs, which indeed student research, due to the particular circumstances of the researcher, is no exception.

(vi) The research was conducted in Iran, and we do not know how much it is coordinated with other countries. Still, we tried to solve this problem by using different research sources and their statistical sources, standardizing the research, and bringing this research closer to the real world around the globe.

(vii) The research has been done cross-sectional; because of this, it makes it challenging to conclude causality.

Future work should include the following recommendations:

(i) In RN, consider the concept of responsiveness during COVID-19.

(ii) Improved the model by considering multi-product.

(iii) Considering model with multi-period.

(iv) Solving the model with other methods and compeering it with this method, for example, LP metric method and genetic algorithms optimization.

(v) Considering the uncertainty returned product for the model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Disclosure

The mathematic model is solved with Lingo software. The Lingo code is available and can be present if necessary.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors contributed to development of this study. All authors read and approved the final manuscript.

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