FOUNDATIONS OF COMPUTING AND DECISION SCIENCES
Vol. 48 (2023) No. 3
ISSN 0867-6356
DOI: 10.2478/fcds-2023-0011 e-ISSN 2300-3405

Designing a Tri-Objective, Sustainable, Closed-Loop, and Multi-Echelon Supply Chain During the COVID-19 and Lockdowns

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Abstract. This paper proposes a mathematical model of Sustainable Closed-Loop Supply Chain Networks (SCLSCNs). When an outbreak occurs, environmental, economic, and social aspects can be traded off. A novelty aspect of this paper is its emphasis on hygiene costs. As well as healthcare education, prevention, and control of COVID-19, this model offers job opportunities related to COVID-19 pandemic. COVID-19 damages lead to lost days each year, which is one of the negative social aspects of this model. COVID-19 was associated with two environmental novelties in this study. positive and negative effects of COVID-19 can be observed in the environmental context. As a result, there has been an increase in medical waste disposal and plastic waste disposal. Multi-objective mathematical modeling whit Weighted Tchebycheff method scalarization. In this process, the software Lingo is used. The COVID-19 pandemic still has a lot of research gaps because it's a new disease. An SC model that is sustainable and hygienic will be developed to fill this gap in the COVID-19 condition disaster. Our new indicator of sustainability is demonstrated using a mixed-integer programming model with COVID-19-related issues in a Closed-Loop Supply Chain (CLSC) overview.

Keywords: Closed-loop supply chain, Coronavirus outbreak, Reverse logistics, Weighted Tchebycheff method

1. Introduction

Recently, there has been a consensus on the need to consider sustainable business. As a result of information management, Sustainable Supply Chain Network Design (SSCND) considers the triple aspects of Supply Chains (SCs) and logistics [80]. There has been severe damage to the SC due to the global COVID-19 epidemic [26]. There has been an unprecedented level of COVID-19 outbreak in global SCs [111]. It is equally important to create a reverse flow for returning products, along with all other aspects of sustainability [59]. There has not been a clear definition of sustainable and green SC up to now [110].

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The possibility should be considered of backflow for returned products with all the demotion of sustainability [59]. By increasing the social impact of networks, profitability and competition can be increased [98]. As the cause of the biggest disruptions in human history, COVID-19 has made the strongest impact on SCs during the recent pandemic. In SCs around the world, pandemics cause chaotic conditions [38]. It is possible to transfer COVID-19 from one person to another very quickly [35]. Prevention of disease begins with preventing infection [101]. Lockdown policy and reduced physical contact are fundamental principles in the COVID-19 confrontation [76]. The CLSC is a new concept in logistics at preventing environmental degradation and resource scarcity. By implementing CLSC, network flows will be controlled, emissions and waste will be reduced, and low-cost production will be achieved. Considering that CLSCs control the material, SC activities can reduce their environmental impact [29]. Growing environmental concerns have made the development of a Green Closed-Loop Supply Chain Network (GCLSCN) a significant challenge [159]. COVID-19 outbreaks are also impacting emissions in a significant way [75]. With environmental protection, client awareness and desires, and carbon policies on the rise, Supply Chain Design (SCD) has become a fundamental objective. [141]. As a result of the COVID-19 pandemic and intensive lockdowns, China reported a reduction in CO_2 emissions [102]. The COVID-19 outbreak was not the first time that big companies were concerned about their sustainability and social responsibility. They expressed concerns about catastrophic events and trade disputes [129]. As a result of the SCs' activities, they are now responsible for their environmental and social effects [15]. The three aspects of sustainability, i.e., benefit to humans, and benefit to our planet must be considered simultaneously. Amid the COVID-19 pandemic, SC must ensure the health and safety of its key employees due to pressure from safety, medical, food, and beverage companies [32].

We recommend the following hygiene protocols:

- In the SC, people with COVID-19 symptoms are assessed daily, and people with symptoms should not be able to continue to participate in any activities. Symptomatic employees should be quarantined until the health department takes appropriate action if they show symptoms at work or after work. Health and safety personnel, along with their managers, should notify the appropriate authorities as soon as a suspicious event occurs.
- It is the responsibility of the person responsible for health at work to handle medical records and sensitive personal information under the law. It is also important for him/her to maintain confidentiality. Keeping daily records of any symptoms or temperature above 37.5 C°, or any presence of other employees, laborers, managers, drivers, or others at the building's entrance and exit.
- A glove, mask, face shield, goggles, and gown must be worn continuously by all personnel interacting with the SC. For employees who engage in high-risk activities, this is particularly important.
- Always provide soap, hand sanitizers with alcohol, cleaning paper, disinfectant for surfaces, and closed trash bins everywhere.
- Place the disposable tissues and face masks in the designated bins.
- Avoid touching money directly during the SC process and use cash instead of a credit card.
- Keeping two meters’ distance between people is a good rule of thumb. Thus, SC

entities organize their shifts according to their programs.

- Incorporate COVID-19 symptoms, hygiene guidelines, and related activities into posters, brochures, and checklists.
- Employees need to notify the administrator and health officer if they have been in contact with a COVID-19-positive person.
- Prevent the spread of infectious and non-infectious waste during the SC by collecting, transporting, storing, and handling it properly.
- Waste COVID-19 will be transported by special vehicles during the SC.
- Don't allow members of SC to share belongings or utilize colleagues' tools or workspace while they are working.
- The SC network should be aerated at least five times per day. When taking a break from work or while eating, try not to gather in a public or private area. Every SC facility should be equipped with a shower. Organizing meetings online rather than in person. Working hours should be reduced as much as possible. Minimizing office hours and allowing employees to work from home. Traveling along the SC will prevent unnecessary displacement [133].

Figure 1.The different types of persistence of coronaviruses on a surface [70,139,58,125, 56]

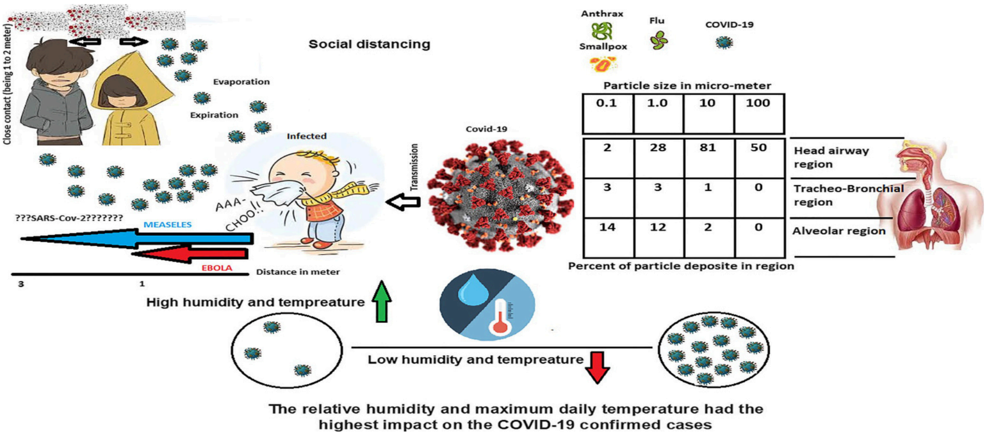

Figure 2. The effects of humidity and temperature on the activity of 2019-nCoV were investigated. These factors include social distancing, close contact, particle size, and the percentage of virus particles deposited in various regions of the upper airway [56]

This Triple Bottom Line (TBL) is suggested in our paper to measure the economic, environmental, and social performance in the COVID-19 condition shown in Figure 3 as follows:

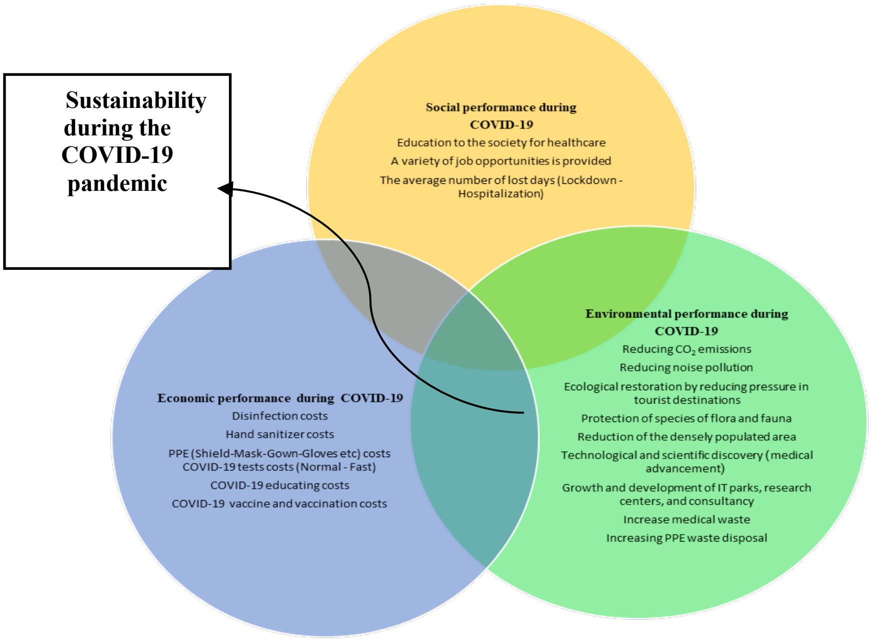

Figure 3.TBL of sustainability in the COVID-19 pandemic

There are five types of facilities provided by the model described above: i) Suppliers and companies that supply, ii) Manufacturing / Remanufacturing / Refurbishing, iii) Collection / Dispatch, iv) Customer Service, and v) Recycling / Landfilling. A forward flow involves the extraction of materials from a supplier and their delivery to factories for production. A new, remanufactured, or refurbished product is transferred forward to meet the customer's needs. When customers return products, they are collected and shipped to collection/distribution centers, which inspect and categorize them, and then send them to factories for remanufacturing and refurbishment, while the rest are sent to recycling and landfills. An economic, environmental, and social model incorporating indicators of performance in COVID-19 has been developed in this paper to increase SC's efficiency. During an outbreak, this study aims to develop a hygienic SSC model to illustrate the trade-off between economic, environmental, and social problems.

2. Literature Review

An investigation of related work is divided into four subsections in this literature review. We are focusing on the economic aspects of the first subsidiary. Environmental aspects are discussed in the second subsection. Therefore, we are reviewing the social aspects in the third subsection. The SC also considers the COVID-19 pandemic in the last subsection. In Table 1, we summarized the different kinds of SC.

2.1 Survey on Recent Research

2.1.1 Perspectives on the economy

There are economic aspects to the SSC's first dimension. Traditional mathematical models of network design were created without considering environmental goals to minimize costs or maximize profits. Using product quantities to minimize the total cost for network design [138]. The concept of cost, delivery time, and quality is taken into consideration [24]. Presented a model for inventory planning and production with a profit maximization objective [7]. An approach to CLSC design that considers the storage level and maximizes profit [118]. Maximizing profits by considering RLs [126]. A multi-product network is designed to minimize the total cost under uncertainty. Using multi-echelon inventory methods to maximize CLSC profit [153]. Presenting the mixed-integer linear programming (MILP) model in CLSC to minimizing the overall cost under uncertain conditions [108]. Using the multi-objective method, the authors propose a new approach to controlling the costs in the supply chain network (SCN) [27]. A stochastic SC model incorporating profit and quality is illustrated and evaluated [43]. In [23,97] researchers examined the cost and total service time. Study the effect of advertising policy coordination between retailers and manufacturers in the supply chain on competition [13]. Garai et al [45] suggested that CLSCs should focus on reverse chains considering financial self-reliance. Optimal net profits and reverse chain layer are two objectives for modeling the CLSC [44]. Under disaster situations, design a CLSC that focuses on price and economic dominance.

2.1.2 Perspectives on the environment

Environmental protection is the second dimension of the SSC. Promoting public awareness of environmental issues has increased enthusiasm for environmentally friendly SCNs [109]. In recent years, this field has been moving toward Green Supply Chain Management (GSCM). Researchers at Waltho et al researched articles on Green Supply Chain Network Design (GSCND), carbon emissions, and environmental policies, demonstrating their significance. Environmental aspects of SSCND have been considered by researchers [140]. Fuel and energy consumption were also addressed by Zhalechian et al [153]. Water footprint was suggested by Zhao a criterion for measuring water use related to human consumption [159]. A closed-loop (CL) system (recycling, disposal, and remanufacturing) is described in the article [8,33]. Reverse Logistics Networks (RLNs) are considered the most efficient in the MILP model proposed by Alumur et al [9]. Arampantzi [12] and Littman & Burwell [82], investigated noise pollution rate and solid / water waste generation. Based on backward logistics, Kannan et al. discuss emissions in open facilities and transportation [71]. Determine a maximum CO_2 emissions limit for each product manufactured and recycled during transportation. Martí et al mention that CO_2 emissions can be attributed to many factors, including raw materials, production, storage, and transportation [90]. According to Zeballos et al, CLSC design should take into account the costs of different kinds of shipping [152]. In the CLSC, emissions are considered from production, warehousing, disposal, and recycling [95,130]. Incentives for producers and retailers to reduce emissions through a carbon tax [84]. A cap-and-trade system in SC should consider outsourcing issues. Coordination and decision-making SC considering cap-and-trade [143]. As of now, COVID-19 has achieved the maximum reduction in CO_2 emissions. The lockdowns helped keep COVID-19 at a controlled rate, but they also severely reduced human activity [101]. In response to the lockdown limitations, the projected harvest of trees has been temporarily halted, reducing CO_2 emissions [132]. A major part of emissions may be reduced during this pandemic as a result of the lockdown, which has stopped all major transportation proceedings. Carbon tax optimization and CO_2 reduction in SC [78]. Considering renewable energy as a means of reducing environmental pollutants [46]. The environmental and economic impact of recycling in CLSCs [93]. Considering the environmental responsibilities of SCs by [145]. In the SC, resilience, and uncertainty are considered under the environment [77]. The design of a dual-channel CLSC model for green CLSCs [73]. Consideration of remanufacturing, recycling, and reducing environmental pollution during SC [158]. Life Cycle Assessments (LCAs) measure environmental impacts [21]. The design of a SC to control CO_2 and SO_2 emissions has been described in [131]. Two-tier supply chain with backorders managed by green vendors using Epsilon constraint and NSGA-II [37]. Designing a CLSC for perishable products considers minimizing CO_2 release [49]. Researched the environmental aspects of Municipal Solid Waste (MSW) management concerning Greenhouse Gas (GHG) release [137]. Optimization of green logistics systems using two-echelon hierarchical location-allocation-routing [135].

2.1.3 Perspectives on the social

During the past few years, both universities and industry have paid attention to the social side of SSC. There are three aspects of sustainability that are considered in the SSC for beef SC [50]. The SSCND papers have been summarized by Eskandarpour et al [36]. The expansion of regional balancing and regional commitment are among the aspects of societal commitment [40,149]. Zhang et al. [155] Another social purpose is to satisfy customers. Employee satisfaction and workplace environments have been highlighted by several scholars [12,52]. Social and economic aspects of modeling and optimizing the sustainable pharmaceutical supply chain under uncertainty. A sustainability framework should be considered when designing the CLSC network [51]. Development of a sustainable CLSC model using ε-constraint methods [123]. To be sustainable and resilient, it was suggested to create a CLSC that consumed water and air pollution [6]. Based on Nayeri et al [105], created a SCLSCN. Optimizing sustainable and resilient CLSC designs by modeling conditional value at risk [85]. A mathematical model for evaluating closed-loop supply chains' robustness and efficiency [151]. Using Lagrange relaxations and fix-and-optimize approaches, develop a robust model for SCLSCN [86]. For a case study of a real-life COVID-19 outbreak, Abbasi et al measured the sustainability of the supply chain [1].

2.1.4 Perspectives on COVID-19

The focus of this section is on COVID-19 and SC. Dmitry Ivanov and Ajay Das [62] investigated COVID-19 and SC resilience. When the COVID-19 pandemic broke out, Rowan & Laffey investigated the issue of inadequate SC for personal protective equipment [112]. Developing a global perspective on COVID-19 [64]. By [57], food SCs played a role in COVID-19 outbreaks. Researching intertwined supply networks in the COVID-19 situation [62]. Ranking of hospitals for patient satisfaction criteria in COVID-19 disaster [127]. Demand and supply during and after COVID-19 [30]. COVID-19 SC risk management model [122]. Redesigning SC in the COVID-19 epidemic [103]. During and after COVID-19, efficient logistics and SCM are essential [61]. Developing a model for the survivability of SSCs of small and medium companies in the COVID-19 outbreak [16]. The COVID-19 SSC drivers are being investigated to address SC disruptions [72]. Reduction of COVID-19 risk by artificial intelligence in SC [104]. Create a disaster relief SC with multiple objectives, multiple products, and multiple periods to satisfy PPE demands under COVID-19 [99]. COVID-19 pandemic relief using IoT [146]. During COVID-19, intertwined supply networks were studied [62]. A patient satisfaction survey was conducted in the aftermath of the COVID-19 disaster. [127]. COVID-19 supply and demand comparison [30]. SC risk management under COVID-19 conditions [122].SC was redesigned in response to the COVID-19 epidemic [102]. Effective SCM and logistics during and post COVID-19 [61]. Developing a model to predict small and medium companies' survivability during the COVID-19 outbreak [16]. To tackle SC disruptions in COVID-19, we are investigating SSC drivers [71]. Reducing COVID-19 risk with artificial intelligence in SC [104]. Prepare a disaster relief SC that meets the PPE requirements of COVID-19 with multiple objectives, multiple products, and multiple periods. COVID-19 relief SCN created using IoT [148]. An analysis of a COVID-19 SCN problem with multi-objectives, multi-levels, and multiple products [52]. Designing a stochastic model for optimizing blood SC based on simulations in the COVID-19 situation [128]. A MILP approach to building a sustainable and resilient healthcare system during COVID-19 [136]. Under COVID-19, the emergency department will receive the following resources [66]. In an Iranian hospital under COVID-19 conditions, an analysis of the humanitarian supply chain is presented [67]. Accordingly, to the outbreak, a multi-level model is proposed [48]. Meta-heuristic algorithms are used to solve a SCLSCN for a face mask under COVID-19 [136]. An enhanced survivability model for SSCs during and after the COVID-19 pandemic is being developed [124].An analysis of COVID-19 challenges and their mitigation strategies with a dynamic capability framework [111]. COVID-19 impacts on SCs management were addressed through a robust time and cost tradeoff [87]. Research on disruptions in SC and shocks in social and economic aspects during COVID-19 [29]. The AHP method is used to make SC resilient in the COVID-19 condition. A single firm and SC are responsible for reshoring decisions triggered by COVID-19 [17]. During the COVID-19 pandemic, factors affecting the survivability of SSCs were assessed empirically [16]. The implementation of a framework for improving sustainable supply chains' survivability during and after COVID-19 [124]. A study of disruptions to the sustainable supply chain during COVID-19 was conducted [10]. Enhancing supply chain sustainability in an emerging economy during the COVID-19 pandemic [72]. Using artificial intelligence to assess COVID-19's impact on agricultural supply chains [104]. Lessons from COVID-19 outbreaks and strategies for reducing the threat of the disease [111]. An analysis of the design of a sustainable end-of-life product recovery network (RN) in light of the COVID-19 pandemic by **Abbasi et al** [1]. **Abbasi et al** said in the event of an outbreak of COVID-19, planning a sustainable supply chain will reduce carbon emissions [2]. An analysis of the Iranian automotive industry's green closed-loop supply chain networks (GCLSCNs) during the coronavirus outbreak by **Abbasi et al** [3]. **Abbasi et al** applied performance measurement to the SSC during the COVID-19 [4]. Table 1 compares and analyzes the related investigations.

Table 1. Investigations of related works

References	Open-loop	Closed-loop	Single objective	Multi-objectives	Economic aspects	Environment aspects	Social aspects	COVID-19
[138]	*		*		*			
[27]	*		*		*			
[42]		*		*	*	*		
[7]	*		*		*			
[50]	*			*	*	*	*	
[142]	*		*		*	*		
[67]	*			*	*	*		
[116]	*			*	*	*		
[106]	*			*	*	*		
[154]		*		*	*			
[19]	*		*		*			
[33]		*		*	*	*	*	
[110]	*		*		*			
[55]		*		*	*	*	*	
[25]	*			*	*			
[96]	*			*	*	*		
[134]	*		*		*			

[117]		*		*	*	*	*	
[79]	*			*	*	*		
[74]		*		*	*	*		
[39]		*		*	*	*		
[100]	*			*	*			
[144]		*		*	*	*		
[145]	*			*	*	*		
[93]		*		*	*	*		
[73]		*		*	*	*		
[6]		*		*	*	*	*	
[136]	*			*	*	*		*
[5]		*		*	*	*	*	
Our investigation		*		*	*	*	*	*

2.2 The research gaps

In summary, the proposed paper covers some literature gaps and categorizes innovation as follows:

1) Designing a SC in compliance with all health protocols
2) Designing a new SSC that considers the pandemic from three perspectives:
   - To develop the economic aspects of COVID-19, the hygiene costs must be added to the normal conditions.
   - Develop the environmental aspects, COVID-19 and lockdown should be considered from both a positive and negative perspective.
   - Developing the social aspects considering the COVID-19 damage to society.
3) In the COVID-19 outbreak, the distribution center and collection center are merged to prevent physical contact with customers.
4) The CLSC framework integrates issues related to the COVID-19 pandemic in a MOMIP model.
5) Discuss the managerial implications of the mathematical model.

To fill this gap, this investigation attempts to develop a new and hygienic SSC model.

3. Mathematical Model

The SSC focuses on three aspects of sustainability. In addition to saving costs and improving economic efficiency, recycling activities are an environmentally friendly process. An integrated forward and reverse flow is provided by the CLSC. According to this paper, the Distribution Center (DC) is incorporated with the Collection Center (CC) during the outbreak of COVID-19, to reduce building costs, reduce carbon dioxide emissions, decrease environmental pollution, as well as preventing physical contact with customers. Furthermore, monetary expenditures for a specific SC design can be calculated as a total cost measure. To create the SSC, a mathematical modeling method is used to measure environmental and social efficiency indexes. By using the model, we will be able to design the SC optimally, identify which facilities should be included in the network, and recognize the flow of goods items among different levels. To determine the best network scenario, it is necessary to consider both the pandemic and lockdown costs. In addition to providing useful information to DMs, the environmental and social aspects of SC activities (extracting, producing, remanufacturing, refurbishing, distributing, collecting, recycling, landfilling, and transporting) ultimately result in more sustainable decisions during pandemics.

3.1 Problem statement and assumptions

Five types of facilities are described in the mathematical model above:1) Suppliers and companies that supply **(S)**,2) Manufacturing / Remanufacturing / Refurbishing **(MR)**,3) Collection / Dispatch **(CD)**,4) Customer Service **(CS)**,5) Recycling / Landfilling **(RL)**. Factory production begins with the extraction of raw materials from supplier centers. Manufacturers, remanufacturers, and refurbishes deliver their goods in a forward manner to meet the demands of their clients. During the reverse flow, clients return goods to Collection / Dispatch centers, where they are inspected and divided into goods that can be remanufactured and refurbished, which go to a Manufacturing / Remanufacturing / Refurbishing facility, while others are disposed of in a Recycling / Landfilling facility. In Figure 4, you can see a smaller version of our network. Assumptions are made to build the model: It is disposed of according to the calculated percentage of total demand.

- SC considerations are taken into account thoroughly when dealing with COVID-19 outbreaks.
- Distribution and Collection Centers have been merged.
- There was never a shortage of customer demand.
- The COVID-19 hygiene protocol ensures that all returned goods that need to be disposed of are successfully recycled and landfilled.
- Returns and demand are certain.
- The locations of *MR* are potential.
- The locations of *CD* are potential.
- The locations of *RL* are potential.
- The locations of *S* and *CS* are fixed.
- A feasible distance should exist between the nodes of the network, and for each connection, there are several delivery options.
- Job opportunities are categorized into two types: fixed and variable normal opportunities, and fixed and variable COVID-19 opportunities.
- The health and safety of workers are measured by workday lost. it should be arranged. The average number of lost days caused by normal damages (e.g. accidents, normal hospitalizations), and the average number of COVID-19 damages and mortality rate of the infected population (e.g. physical and mental coronavirus damages).

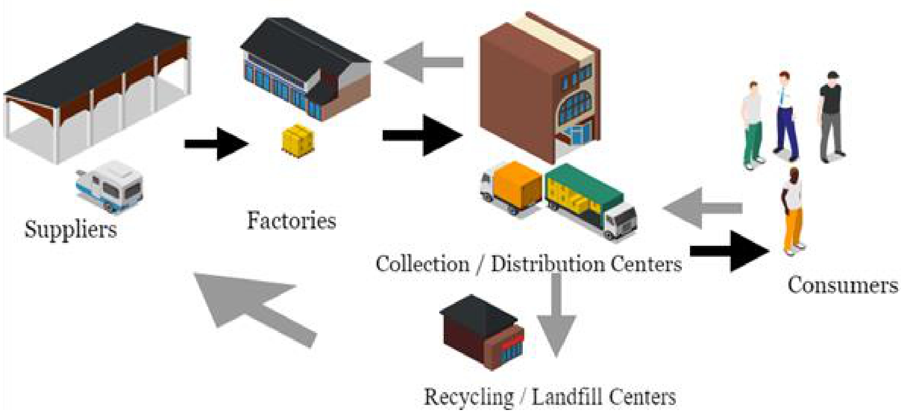

Figure 4. The closed-looped, multi-echelon supply chain is depicted

3. 2 An overview of the model components

There are sets, parameters, and variables in the SC model. An example of model parameter is a technical parameter, economic parameters, environmental parameters, and social parameters. A binary decision variable and a continuous decision variable are used in the model to allocate goods items to the SSC network.

3.3 Formulation process

An Objective Function (OF) and a constraint are two parts of the mathematical model's formulation. As part of the mathematical model, three objectives exist, minimization of the total cost (economic perspective), minimization of the negative effects on the environment (environment perspective), and minimization of the negative effects on society (social perspective) in the COVID-19 conditions and lockdown days in the SC.

Indications

s : Index of existing suppliers and companies that supply materials $s \in S$ = {1,2, 3..., s},

f : Index of potential manufacturing / remanufacturing / refurbishing centers $f \in F$ = {1,2, 3..., f},

i : Index of collection / dispatch centers $i \in I$ = {1,2, 3..., I},

b : Index of recycling / landfilling centers $b \in B$ = {1,2, 3..., B},

c : Index of customer service and centers $c \in C$ = {1,2, 3..., c},

ts : Index of alternatives to delivery from suppliers $ts \in TS$ = {1,2, 3..., ts},

tf : Index of alternatives to delivery from manufactures $tf \in TF$ = {1,2, 3..., tf},

ti : Index of alternatives to delivery from collection / dispatch centers $ti \in TI$ = {1,2, 3..., ti},

tc : Index of alternatives to delivery from customers' centers $tc \in TC$ = {1,2, 3..., tc},

tb : Index of alternatives to delivery from recycling / landfilling centers $tb \in TB$ = {1,2, 3..., tb},

Parameters

d_c :demand of customer service c,

M_s: Capacity for obtaining,

M_f : Capacity for manufacturing,

M_i: Capacity for collection/ dispatching,

M_b : Capacity for recycling / landfilling,

Mr_f: Capacity for remanufacturing/refurbishing,

$MN_{dismantled}$: Amount of returned goods that will be remanufactured,

$MN_{disposed}$: The amount of returned goods that will be recycled or disposed of,

δ_{sf} : Distance between specified supplier and *MR*,

δ_{fi} : Distance between specified *MR* and *CD*,

δ_{if} : Distance between specified *CD* and *MR*,

δ_{ic} : Distance between specified *CD* and *CS*,

δ_{ci} : Distance between specified *CS* and *CD*,

δ_{ib} : Distance between specified *CD* and *RL*,

δ_{bs} : Distance between specified *RL* and supplier,

$w_{n_{ld}}$: An indicator of how much weight to give to the total lost days caused by nominal damages to the works.

w_{jo} : The weighting factor used to calculate COVID-19 damages is the total lost days, $w_{COVID-19_{ld}}$: The number of normal job opportunities is weighted by the number of normal jobs,

$w_{COVID-19_{jo}}$: Total number of COVID-19 job openings weighted by this factor,

θ_f : In the COVID-19 pandemic, there is a fixed cost for the opening of the MR ***f***,

θ_i : In the COVID-19 pandemic, there is a fixed cost for the opening of the CD ***i***,

θ_b : In the COVID-19 pandemic, there is a fixed cost for the opening of the RL ***b***,

V_s : Costs associated with obtaining materials from supplier ***s,***

V_f :Costs associated for creating an item of goods in the MR ***f,***

V_i :Costs associated for dispatching an item of goods in the CD ***i,***

Vr_i :Costs associated for collecting an item of the returned goods in the CD ***i,***

V_b :Costs associated for recycling and landfilling an item of the returned goods in RL ***b,***

Vr_f :Costs associated for recovery an item of the returned goods in the MR ***f,***

TCO_{sf}^{ts} : Delivering prices of an item of material from the supplier ***s*** to MR ***f*** with delivering option ***ts***,

TCO_{fi}^{tf} : Delivering prices of an item goods from MR ***f*** to CD ***i*** with delivery option ***tf***,

TCO_{ic}^{ti} : Delivering prices of an item of goods from CD ***i*** to CS ***c*** with delivery option ***ti***,

TCO_{ci}^{tc} : Delivering prices of an item of the returned goods is collected from CS ***c*** to CD ***i*** with delivery option ***tc,***

TCO_{if}^{ti} : Delivering prices of an item of the returned goods is accessible for recovering from CD ***i*** to MR ***f*** with delivery option ***ti***,

TCO_{ib}^{ti} : Delivering prices of an item of returned goods that is not suitable for remanufacturing and refurbishing, from CD ***i*** to RL ***b*** with delivery option ***ti,***

TCO_{bs}^{tb} : Delivering prices of an item of recycled goods from RL ***b*** to supplier ***s*** with delivery option ***tb,***

HV_S :Costs related to COVID-19 during obtaining an item of material from the supplier ***s,***

HV_f : Costs related to COVID-19 during producing an item of goods in the MR ***f,***

HV_i : Costs related to COVID-19 during distribution an item goods from the CD ***i,***

HVr_i : Costs related to COVID-19 during collecting, inspecting consolidating, and sorting a unit of the returned goods in the CD ***i,***

HV_b : Costs related to COVID-19 during recycling and landfilling an item of the returned goods in RL ***b,***

HV_{rf} : Costs related to COVID-19 during recovering an item of the returned goods in the MR ***f,***

HTC_{sf}^{ts} : Costs related to COVID-19 during the delivering of an item of material from the supplier ***s*** to MR ***f*** with delivery option ***ts***,

HTC_{fi}^{tf} : Costs related to COVID-19 during the delivering of a unit of goods from MR ***f*** to CD ***i*** with delivery option ***tf,***

HTC_{ic}^{ti} : Costs related to COVID-19 during the delivering of a unit of goods from CD ***i*** to CS ***c*** with delivery option ***ti,***

HTC_{if}^{ti} :Costs related to COVID-19 during delivering of an item of the returned goods from CD ***i*** to MR ***f*** with delivery option ***ti***,

HTC_{ib}^{ti} :Costs related to COVID-19 during the delivering of an item of returned goods from CD ***i*** to RL ***b*** with delivery option ***ti,***

HTC_{ci}^{tc}: Costs related to COVID-19 during the delivering of an item of returned goods from CS ***c*** to CD ***i*** with delivery option ***tc***,

HTC_{bs}^{tb}: Costs related to COVID-19 during the delivering of an item of recycled goods from RL ***b*** to supplier ***s*** with delivery option ***tb,***

e_s : Environmental impacts for extracting an item of material in the supplier ***s***,

e_f : Environmental impact for producing an item of goods in MR ***f***,

e_i : Environmental impact of handling and distributing an item of goods in the CD ***i,***

er_i : Environmental impacts of collecting an item of the returned goods in the CD ***i*** ,

er_f : Environmental impacts of remanufacturing an item of the returned goods in the MR ***f***

e_b: Environmental impacts for recycling and landfilling an item of the returned goods in RL ***b*** ,

$ETCR_{sf}^{ts}$: Environmental impacts by delivery option ***ts*** to send an item of material from supplier ***s*** to MR ***f***,

$ETCR_{fi}^{tf}$:Environmental impacts by delivery option ***tf*** to send an item of goods from MR ***f*** to CD ***i*** for a unit distance ,

$ETCR_{ic}^{ti}$: Environmental impacts by delivery option ***ti*** to send an item of goods from CD ***i*** to CS ***c*** for a unit distance,

$ETCR_{ci}^{tc}$: Environmental impacts by delivery option ***tc*** to collect an item of returned goods from CS ***c*** to CD ***i*** ,

$ETCR_{if}^{ti}$: Environmental impacts by delivery option ***ti*** to send an item of the returned goods to be remanufactured from CD ***i*** to MR ***f***,

ETC_{tb}^{ti} : Environmental impacts by delivery option ***ti*** to send an item of returned goods from CD ***i*** to RL ***b***,

ETC_{bs}^{tb} : Environmental impacts by delivery option ***tb*** to send an item of recycled goods from RL ***b*** to supplier ***s*** for a unit distance ,

LD_f : In MR ***f*** , normal-related lost days on average,

LD_i : In CD ***i,*** normal-related lost days on average,

LD_b : In RL ***b,*** normal-related lost days on average,

$LD-COVID_f$: In MR ***f*** , COVID-19-related lost days on average,

$LD-COVID_i$: In CD ***i,*** COVID-19-related lost days on average,

$LD-COVID_b$: In RL ***b,*** COVID-19-related lost days on average,

JO_f : In MR ***f,*** the number of created fixed and variable job opportunities,

JO_i: In CD ***i,*** the number of created fixed and variable opportunities,

JO_b: In RL ***b,*** the number of created fixed and variable opportunities,

$JO-COVID_f$: In MR ***f,*** the number of new jobs related COVID-19 during manufacturing, remanufacturing and refurbishing,

$JO-COVID_i$: In CD ***i,*** the number of new jobs related COVID-19 during distribution and collection,

$JO-COVID_b$: In RL ***b***, the number of new jobs related COVID-19 during recycling and landfilling,

Decision variables

x_f : If Manufacturing/Remanufacturing/Refurbishing ***f*** is founded, equal 1;otherwise 0.

x_i : If Collection / Dispatch ***i*** is founded, equal 1; otherwise 0.

x_b : If Recycling / Landfilling ***b*** is founded, equal 1; otherwise 0.

Y_{sf}^{ts} : Raw material item sent from suppliers to MR ***f*** with delivery option ***ts***,

Y_{fi}^{tf} : Goods item sent from MR ***f*** to CD ***i*** with delivery option ***tf,***

Y_{ic}^{ti} : Goods item sent from CD ***i*** to CS ***c*** with delivery option ***ti,***

Y_{ci}^{tc} : Returned goods item collected from CS ***c*** to CD ***i*** with delivery option ***tc,***

Y_{if}^{ti} : Returned goods item from CD ***i*** to MR ***f*** with delivery option ***ti,***

Y_{ib}^{ti} : Returned goods item from CD ***i*** to RL ***b*** with delivery option ***ti,***

Y_{bs}^{tb} : Returned goods item from RL ***b*** to supplier ***s*** with delivery option ***tb,***

Objective functions (OFs) and constraints of the supply chain network

$$
\begin{aligned}
Min\, z_1 = (&\sum_{f=1}^{F}\theta_f x_f+\sum_{i=1}^{I}\theta_i x_i+\sum_{b=1}^{B}\theta_b x_b+\sum_{s=1}^{S}v_s\sum_{f=1}^{F}\sum_{ts=1}^{TS}Y_{sf}^{ts}+\sum_{f=1}^{F}V_f\sum_{i=1}^{I}\sum_{tf=1}^{TF}Y_{fi}^{tf}+\sum_{i=1}^{I}V_i\sum_{c=1}^{C}\sum_{ti=1}^{TI}Y_{ic}^{ti} \\
&+\sum_{i=1}^{I}Vr_i\sum_{c=1}^{C}\sum_{tc=1}^{TC}Y_{ci}^{tc}+\sum_{f=1}^{F}Vr_f\sum_{i=1}^{I}\sum_{ti=1}^{TI}Y_{if}^{ti}+\sum_{b=1}^{B}V_b\sum_{i=1}^{I}\sum_{ti=1}^{TI}Y_{ib}^{ti}+\sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS}TCO_{sf}^{ts}Y_{sf}^{ts}+\sum_{f=1}^{F}\sum_{i=1}^{I}\sum_{tf=1}^{TF}TCO_{fi}^{tf}Y_{fi}^{tf} \\
&+\sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{ts=1}^{TS}TCO_{ic}^{ti}Y_{ic}^{ti}+\sum_{c=1}^{C}\sum_{i=1}^{I}\sum_{tc=1}^{TC}TCO_{ci}^{tc}Y_{ci}^{tc}+\sum_{i=1}^{I}\sum_{b=1}^{B}\sum_{tb=1}^{TB}TCO_{ib}^{tb}Y_{ib}^{tb}+\sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{tb=1}^{TB}TCO_{bs}^{tb}Y_{bs}^{tb} \\
&+\sum_{s=1}^{S}HV_s\sum_{f=1}^{F}\sum_{ts=1}^{TS}Y_{sf}^{ts}+\sum_{f=1}^{F}HV_f\sum_{i=1}^{I}\sum_{tf=1}^{TF}Y_{fi}^{tf}+\sum_{i=1}^{I}HV_i\sum_{c=1}^{C}\sum_{ti=1}^{TI}Y_{ic}^{ti}+\sum_{i=1}^{I}HVr_i\sum_{c=1}^{C}\sum_{tc=1}^{TC}Y_{ci}^{tc}+\sum_{f=1}^{F}HVr_f\sum_{i=1}^{I}\sum_{ti=1}^{TI}Y_{if}^{ti}+\sum_{b=1}^{B}HV_b\sum_{i=1}^{I}\sum_{ti=1}^{TI}Y_{ib}^{ti}
\end{aligned}
\quad (1)
$$

$$\sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS} HTCO_{sf}^{ts} Y_{sf}^{ts} + \sum_{f=1}^{F}\sum_{i=1}^{I}\sum_{tf=1}^{TF} HTCO_{fi}^{tf} Y_{fi}^{tf} + \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{ts=1}^{TS} HTCO_{ic}^{ti} Y_{ic}^{ti} + \sum_{c=1}^{C}\sum_{i=1}^{I}\sum_{tc=1}^{TC} HTCO_{ci}^{tc} Y_{ci}^{tc}$$

$$+\sum_{i=1}^{I}\sum_{f=1}^{F}\sum_{ti=1}^{TI} HTCO_{if}^{ti} Y_{if}^{ti} + \sum_{i=1}^{I}\sum_{b=1}^{B}\sum_{tb=1}^{TB} HTCO_{ib}^{tb} Y_{ib}^{tb} + \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{tb=1}^{TB} HTCO_{bs}^{tb} Y_{bs}^{tb})$$

$$Min z_2 = \sum_{s=1}^{S} e_s \sum_{f=1}^{F}\sum_{ts=1}^{TS} Y_{sf}^{ts} + \sum_{f=1}^{F} e_f \sum_{i=1}^{I}\sum_{tf=1}^{TF} Y_{fi}^{tf} + \sum_{i=1}^{I} e_i \sum_{c=1}^{C}\sum_{ti=1}^{TI} Y_{ic}^{ti} + \sum_{i=1}^{I} er_i \sum_{c=1}^{C}\sum_{tc=1}^{TC} Y_{ci}^{tc} + \sum_{f=1}^{F} er_f \sum_{i=1}^{I}\sum_{ti=1}^{TI} Y_{if}^{ti} \qquad (2)$$

$$+\sum_{b=1}^{F} e_b \sum_{i=1}^{I}\sum_{ti=1}^{TI} Y_{ib}^{ti} + \sum_{s=1}^{S}\sum_{f=1}^{F}\sum_{ts=1}^{TS} ETC_{sf}^{ts} Y_{sf}^{ts} \partial_{sf} + \sum_{f=1}^{F}\sum_{i=1}^{I}\sum_{tf=1}^{TF} ETC_{fi}^{tf} Y_{fi}^{tf} \partial_{fi} + \sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{ts=1}^{TS} ETC_{ic}^{ti} Y_{ic}^{ti} \partial_{ic}$$

$$+\sum_{c=1}^{C}\sum_{i=1}^{I}\sum_{tc=1}^{TC} ETCR_{ci}^{ci} Y_{ci}^{tc} \partial_{ci} + \sum_{i=1}^{I}\sum_{f=1}^{F}\sum_{ti=1}^{TI} ETCR_{if}^{ti} Y_{if}^{ti} \partial_{if} + \sum_{i=1}^{I}\sum_{b=1}^{B}\sum_{tb=1}^{TB} ETC_{ib}^{tb} Y_{ib}^{tb} \partial_{ib} + \sum_{b=1}^{B}\sum_{s=1}^{S}\sum_{tb=1}^{TB} ETC_{bs}^{tb} Y_{bs}^{tb} \partial_{bs}$$

$$Min z_3 = w_{nd}[(LD_f x_f + LD_i x_i + LD_b x_b) + w_{COVID-19_{ld}}(LD - COVID_f x_f \qquad (3)$$

$$+LD - COVID_i x_i + LD - COVID_b x_b] - w_{jo}[JO_f x_f + JO_i x_i + JO_b x_b)$$

$$+w_{COVID-19_{jo}}(JO - COVID_f x_f + JO - COVID_i x_i + JO - COVID_b x_b)]$$

$$\sum_{s\in S}\sum_{ts\in TS} Y_{sf}^{ts} \le M_f X_f \qquad \forall f \in F \qquad \textbf{(4)}$$

$$\sum_{f\in F}\sum_{tf\in TF} Y_{fi}^{tf} \le M_i X_i \qquad \forall i \in I \qquad (5)$$

$$\sum_{i\in I}\sum_{ti\in TI} Y_{ib}^{ti} \le M_b X_b \qquad \forall b \in B \qquad (6)$$

$$\sum_{i\in I}\sum_{ti\in TI} Y_{if}^{ti} \le Mr_f X_f \qquad \forall f \in F \qquad (7)$$

$$\sum_{c\in C}\sum_{tc\in TC} Y_{ci}^{tc} \le Mr_i X_i \qquad \forall i \in I \qquad (8)$$

$$\sum_{i\in I}\sum_{tf\in TF} Y_{fi}^{tf} \le \sum_{f\in F}\sum_{ts\in TS} Y_{sf}^{tf} \qquad \forall f \in F \qquad (9)$$

$$\sum_{c\in C}\sum_{ti\in TI} Y_{ic}^{ti} \le \sum_{i\in I}\sum_{tf\in TF} Y_{fi}^{tf} \qquad \forall i \in I \qquad (10)$$

$\sum_{b\in B}\sum_{ti\in TI} Y_{ib}^{ti} \leq \sum_{i\in I}\sum_{tf\in TF} Y_{fi}^{tf}$	$\forall i\in I$	(11)
$\sum_{f\in F}\sum_{ti\in TI} Y_{if}^{ti} \leq \sum_{i\in I}\sum_{tf\in TF} Y_{fi}^{tf}$	$\forall i\in I, \forall f\in F$	(12)
$\sum_{i\in I}\sum_{tc\in TC} Y_{ci}^{tc} \leq \sum_{c\in C}\sum_{ti\in TI} Y_{ic}^{ti}$	$\forall i\in I, \forall c\in C$	(13)
$d_c \leq \sum_{i=1}^{I}\sum_{ti=1}^{TI} Y_{ic}^{ti}$	$\forall c\in C$	(14)
$\sum_{c=1}^{C}\sum_{tc=1}^{TC} Y_{ci}^{tc} \leq d_c$	$\forall c\in C$	(15)
$MN_{disposed}\, d_c \leq \sum_{i=1}^{I}\sum_{tc=1}^{TC} Y_{ci}^{tc}$	$\forall c\in C$	(16)
$\sum_{f\in F}\sum_{ti\in TI} Y_{if}^{ti} \geq MN_{dismanteld} \sum_{c\in C}\sum_{ti\in TI} Y_{ci}^{ti}$	$\forall i\in I$	(17)
$Y_{sf}^{ts}, Y_{fi}^{tf}, Y_{ic}^{ti}, Y_{ci}^{tc}, Y_{if}^{ti}, Y_{ib}^{ti}, Y_{bs}^{tb} \geq 0$	$\forall s\in S, \forall f\in F, \forall i\in I, \forall b\in B,$ $\forall c\in C, \forall ts\in TS, \forall tf\in TF,$ $\forall ti\in TI, \forall tb\in TB, \forall tc\in TC$	(18)
$x_f, x_i, x_b \in \{0,1\}$	$\forall f\in F, \forall i\in I, \forall b\in B$	(19)

Subject to:

Objective Functions

Eqs (1) - (3) explain how the OFs are mathematically formulated. There are four costs in total (fixed, variable, delivery and hygiene). During the COVID-19 and lockdown periods, the total effects on the environment are calculated by taking into account the negative and positive effects caused by extracting materials, producing, recovery (remanufacturing and refurbishing), recycling, landfilling, and delivery. By subtracting the number of lost days and the number of job opportunities created across SC during COVID-19, the total bad social impact can be calculated.

Constraints

In the mathematical model, the constraints are given by equations (4) - (19)*;* Constraint (4) shows the maximum number of row material items that can enter a *MR* from each supplier should be either less or the same as the maximum capacity of that *MR*. A *CD's* maximum capacity should not exceed the number of goods items that enter a *CD* via each of the *MRs* via each of the delivery options, according to constraint (5). As described in constraint (6), the total returned goods to be recycled, incinerated, or landfilled collected via each delivering method to an *RL* should not exceed the *RL's* maximum capacity. According to constraint (7), the total returned goods delivered from a *CD* to each *MRs* should be less than or equal to the maximum capacity for remanufacturing and refurbishing of that *MR*. According to constraint (8), the total returned goods delivered. from a *CS* to each *CD* should not exceed the maximum collection capacity of those *CDs*. According to constraint (9), the total goods items that the factory delivered to a *CD* via each transportation option should be lower or equal to the total raw material items that a supplier deliver to a *MR*. According to constraint (10), the total goods delivered from a *CD* to each *CD* via each delivery option should be lower or equal to the total goods delivered from a factory to each *CD*. According to constraint (11), there should be no more than one *RL* per *CD* delivered via each delivery method. According to constraint (12), a *CD's* total number of returned goods items delivered via each delivery option should be lower or equal to a *MR's* total number of returned goods items delivered via each delivery option. According to constraint (13), the number of returned goods delivering from a *CS* to each *CD* via each delivery option ought to be lower or equal to the number of product items delivered from each *CD* to each *CS*. Constraint (14) stipulates that there must be an equal or greater number of goods items distributed from each *CD* via each delivery method to satisfy the demand of a customer. According to constraint (15), the total goods items returned from a *CS* to each *CD* should be less than the demand from the customer. Constraint (16) specifies that the number of units to be recycled, incinerated, and disposed of by each *CS* via each delivery option should equal or exceed the minimum percentage of restitution about the total demands of the respective *CS*. According to constraint (17), the total refurbished and remanufactured goods items that will be delivered by each transportation method to each *MRs* from a *CD* should be greater or equal to the minimum percentage of remanufactured goods items from the total amount of returned goods. According to constraint (18), the total raw materials, goods, and returned goods that flowed from a supplier to a *MR* through delivery options, from a *MR* to a *CD* through delivery options, from a *CD* to a *CS* through delivery options, from a *CS* to a *CD* through delivery options, and between a *CD* and *RL* and *MR* through delivery options should be zero or greater. In constraint (19), the potential of a location is represented by a binary number.

3.4 Solution approach for scalarization

The traditional way to solve MOOP[3] is scalarization, which involves formulating a SOOP[4] associated with the MOOP [69,47].

$$\min\ (f_1(x)\ \ldots, f_p(x))$$
$$x \in X$$

The Weighted Tchebycheff Method

min Υ

Subject to:

$w_1(f_1 - z_1^{**}) \leq w_2(f_2 - z_2^{**}) \leq \cdots \leq w_n(f_n - z_n^{**}) \leq \Upsilon$ Constraints

---

[3] Mulit-objective optimization problem

[4] Single objective optimization problem

where $w_1 \geq 0$, $w_2 \geq 0$…and w_n weights such that $w_1 + w_2 + \ldots w_n = 1$, f_1, $f_2 \ldots f_n$ the objective functions, and $z^* = (z_1^{**}, z_2^{**} \ldots z_n^{**})^T = (\min f_1, \min f_2 ... \min f_n)$ is a reference point (an approximation to the ideal vector);

4. Case Study of a Real-life Situation

It was confirmed on 19 February 2020 that the first COVID-19 cases had been reported in Iran. During the analysis of the case study, the model's validity and functionality are evaluated. In addition to surveying Iranian companies, we interviewed the SC manager. A Real-life case study has been conducted to evaluate the model's effectiveness. A model's accuracy and functionality are evaluated based on the data for the considered case study. In this investigation, the network consists of five kinds of facilities. Potential location of supply chain echelons: *F, CD, RL*, and existing *S* and *CD*. For a better understanding of the subject, Figure 5 was designed.

Figure 5. Schematic of real SC on the COVID-19 outbreaks

Table 2. Solution of the SSC model with LINGO and different objective weights in the COVID-19 pandemic

Objective	$\Sigma w_i = 1$	$\Sigma w_i = 1$	$\Sigma w_i = 1$
Economical weights	0.7410	0.2007	0.0583
Environmental weights	0.2007	0.0583	0.7410
Social weights	0.0583	0.7410	0.2007
Objective 1	Z^*_1= 0.3204112E+14	Z^*_1= 0.4099551E+14	Z^*_1= 0.27804412E+14
Objective 2	Z^*_2=0.2812001E+14	Z^*_2=0.2030197E+14	Z^*_2=0.20010500E+14
Objective 3	Z^*_3=0.1954150E+14	Z^*_3=0.1008101E+14	$Z\ ^*_3$=0.2077411E+14

5. Computational Tests

5.1 Trade-off between objective functions

To perform the computation, Lingo software is used. Weighted Tchebycheff method are used to determine different POF approximations. There are three weights because there are three objective functions. There is a pattern in which w_1, w_2, and w_3 are multiplied by zero and $w_1 + w_2 + w_3$ are equal to one. OFs are ranked according to their performance weights and optimized values in Table 3.

Table 3. Performances weights and optimization value of economic, social, and environmental aspects

Weights	First Objective	Second Objective	Third Objective
$(w_1=0.1,w_2=0.2,w_{3=}0.7)$	1327819	7918724	8126539
$(w_1=0.1, w_2=0.7, w_{3=}0.2)$	1582739	7591820	8092817
$(w_1=0.2, w_2=0.7,w_{3=}0.1)$	1789261	6921025	7728162
$(w_1=0.5, w_2=0.2, w_{3=}0.3)$	2091876	6812001	7021291
$(w_1=0.7, w_2=0.1, w_{3=}0.2)$	2318273	6615432	6821729
$(w_1=0.4,w_2=0.2,w_{3=}04)$	2587654	6419082	6777189
$(w_1=0.2,w_2=01,w_{3=}0.7)$	3098276	6314256	6610918

$(w_1=0.2, w_2=0.3, w_{3=}0.5)$	3521789	6200621	6324151
$(w_1=0.4,w_2=0.4,w_{3=}02)$	5018270	6019280	6262710
$(w_1=0.5, w_2=0.3, w_{3=}0.2)$	5513218	5819203	6187290
$(w_1=0.3, w_2=0.2, w_{3=}0.5)$	5987001	5718254	5287391
$(w_1=0.6, w_2=0.2, w_{3=}0.2)$	7098712	5512879	4217265
$(w_1=0.2,w_2=0.4,w_{3=}04)$	7345321	5419028	3829861
$(w_1=0.2, w_2=0.6, w_{3=}0.2)$	8213456	5312470	3029817
$(w_1=0.2, w_2=0.6, w_{3=}0.6)$	9087654	5012678	2398102
$(w_1=0.7, w_2=0.2, w_{3=}0.1)$	9102871	4022265	2019827
$(w_1=0.2, w_2=0.5, w_{3=}0.3)$	9512341	3700091	1572836
$(w_1=0.3, w_2=0.5, w_{3=}0.2)$	11028716	3200124	1001000

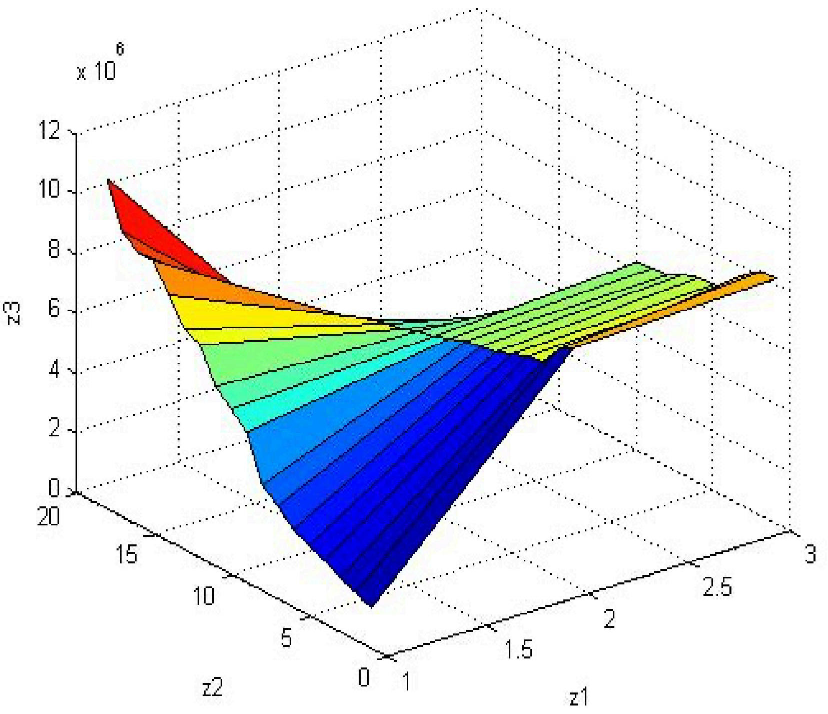

Figure 6. Pareto frontier for case study (Z1, Z2&Z3)

The Pareto front (Figure 6) of the problem was explained and it was found that the proposed model can provide an effective Pareto solution. The results of this investigation indicate the suggested model and its solution approach have acceptable efficiency.

5.2 Problem test

A number of numerical examples are used to evaluate the performance of the SSC in various dimensions. In this regard, 15 numerical examples are provided. For these test problems, Tables 4 & 5 provide dimensional information and show the results. In this sensitivity analysis, we have taken into account the matter that there are a fixed number of delivery options.

Table 4. Dimensions of problem

Dimensions	*Problems*	*Customers*	*Collections & Distributions*	*Factories*	*Recycling & Landfills*	*Suppliers*
small	P1	4	2	1	2	1
	P2	5	3	2	2	3
	P3	6	3	2	3	4
	P4	8	4	3	3	4
	P5	9	5	4	5	5
medium	P6	10	6	5	6	6
	P7	13	7	5	7	6
	P8	15	7	6	7	6
	P9	17	8	6	8	8
	P10	20	8	6	10	9
large	P11	22	9	7	12	10
	P12	23	9	9	13	11
	P13	25	10	11	13	12
	P14	30	11	15	14	13
	P15	40	11	15	14	16

Table 5. Results of different solving

Problems	***Achieved the optimal economic values***	***Achieved the optimal environmental values***	***Achieved the optimal social values***	***CPU time (Seconds)***
P_1	2718736	5524136	2145.022	0.13
P_2	3028172	6241325	2409.100	0.14
P_3	3241526	7902654	2800.333	0.16
P_4	4012543	8124352	2509.133	0.16
P_5	4521782	8976542	2407.280	0.17
P_6	512378.1	9021876	2922.111	0.19
P_7	552172.2	9026541	3209.010	0.22
P_8	6021827	9102985	3245.440	0.22
P_9	6231425	10298765	4900.010	0.25
P_{10}	6211289	11092876	4911.346	0.27
P_{11}	8521728	10098765	5688.110	0.27
P_{12}	9021826	10021087	5590.980	0.27
P_{13}	9220028	10014236	6011.210	0.29
P_{14}	12654327	12987654	6797.100	0.31
P_{15}	14254367	15265432	7207.001	0.33

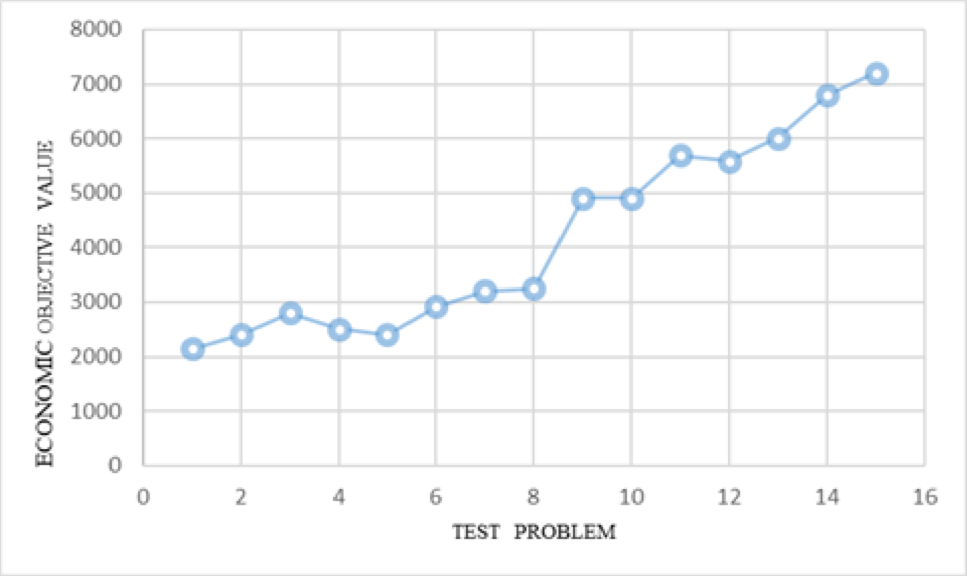

Figure 7. Economic objectives' values

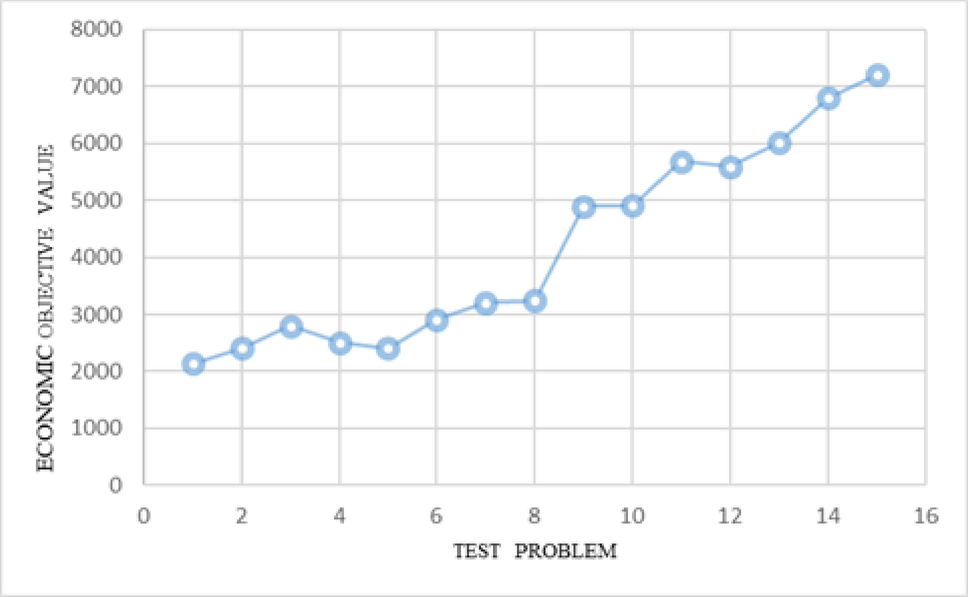

Figure 8. An environmental objective's values

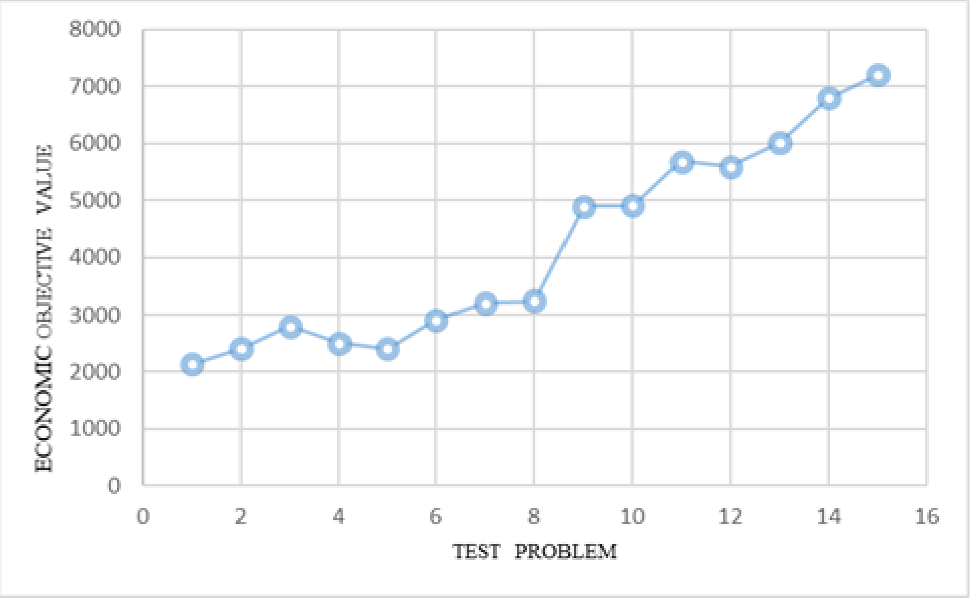

Figure 9. Social objectives' values

In Figures 7, 8, and 9, we see that the optimal value of each OF grows as the issue's dimensions' increase. The rate of rising varies according to the case, and these increases are not linear. Our mathematical model can be used to solve problems in small, medium, and large dimensions.

5.3 Sensitivity analysis

Analyzing the sensitivity of a model's parameters is carried out to gain insight into its effects. A comparison between the two scenarios is made of the economic, environmental, and social objectives functions. Our analysis of the optimization of solutions was based on the change in the conditions of the problem. Several scenarios, such as fallow, are shown in Tables 6,7 & 8 and Figures 10,11 & 12.

Table 6. Under different conditions, the economic objective function's optimization value

Ordinary situation	*COVID-19 situation*
Z* = 4263571	Z* =5020981

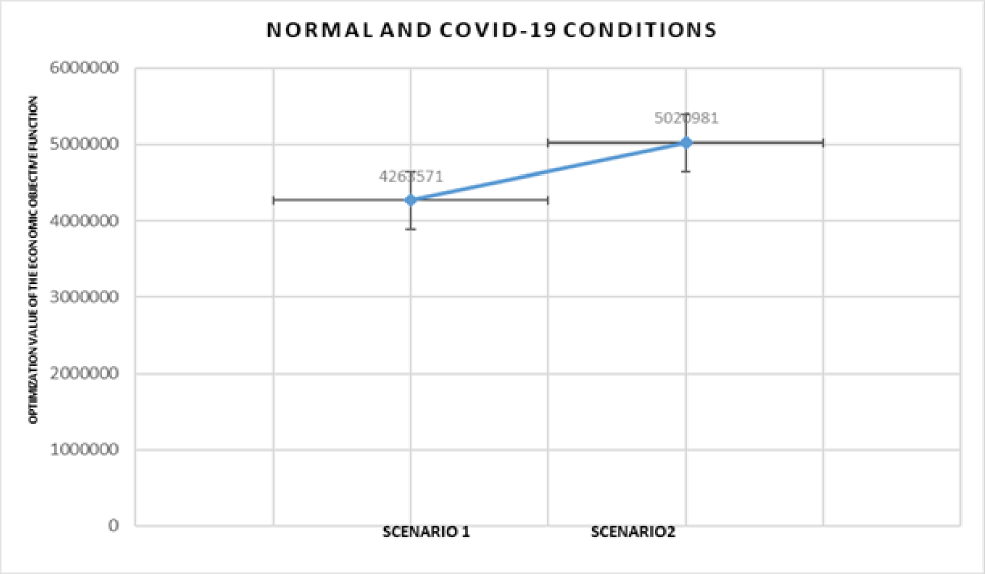

Figure 10. Economic aspect for ordinary and COVID-19 situations

Table 7. Under different scenarios, the environmental objective function's optimization value

Ordinary situation	*COVID-19 situation*
Z* = 2786549	Z* =1987652

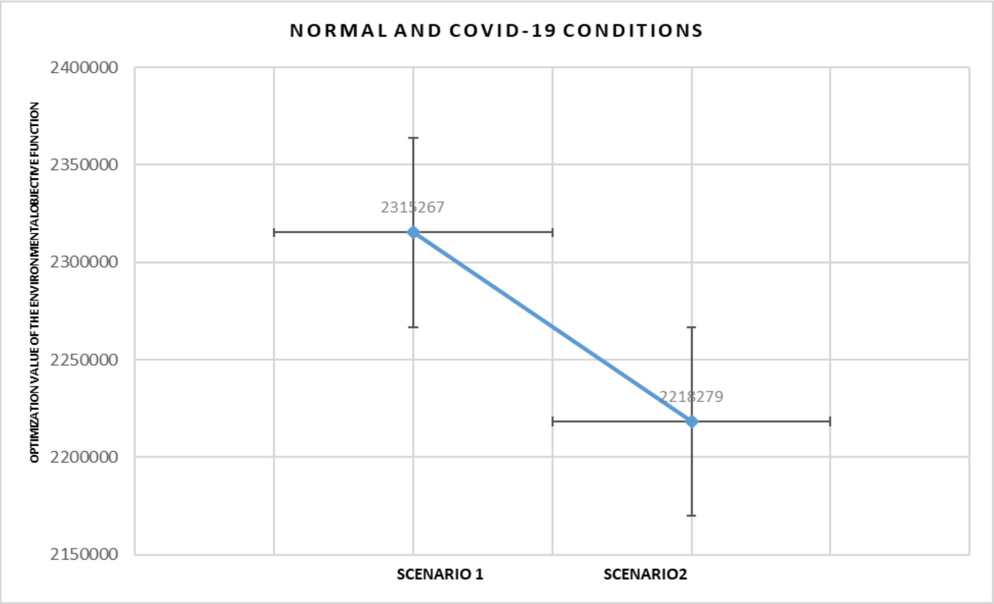

Figure 11. Environmental aspect for ordinary and COVID-19 situations

Table 8. Under different scenarios, the optimization value of the social objective function

Ordinary situation	***COVID-19 situation***
Z* = 8109287	Z* = 908732

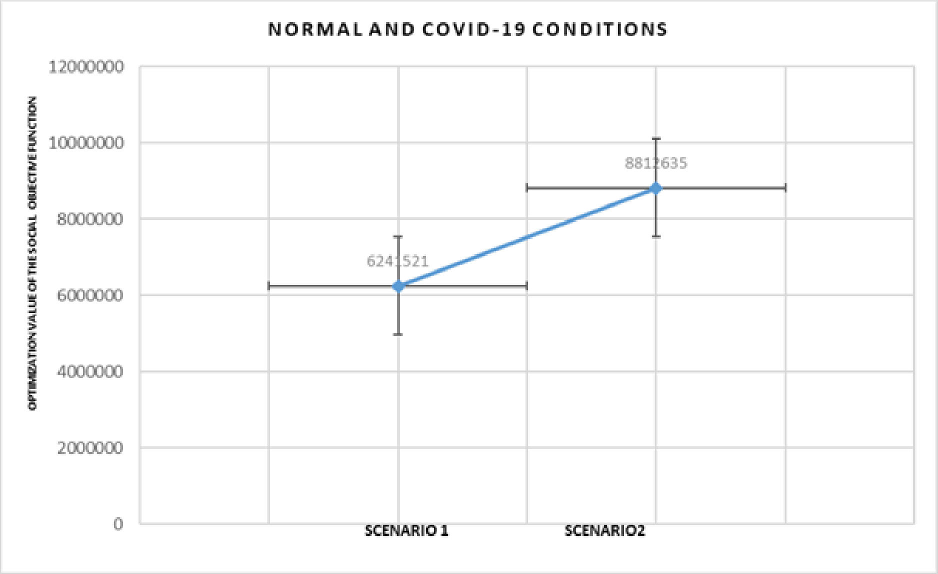

Figure 12. Social aspect for ordinary and COVID-19 situations

The proposed network has improved the environmental sustainability of the SC. Compared with the normal scenario, the COVID-19 scenario provides a better optimization value for the environment objective function. Economic objective function optimizes better under the normal scenario than under COVID-19. Compared to COVID-19, a normal scenario has a better optimization value. A detailed analysis of COVID-19's sustainability effects is presented in Table 9.

Table 9. Results of the analysis of the indicator of sustainability for SSC in the COVID-19 in our study are as follows

Number	Descriptions	Analysis	Effect
1.	The costs of disinfection and sanitization during the SC.	Increasing in COVID-19	Negative
2.	It includes the costs of preparing personal protective equipment (shield, mask, gown, gloves, and the like) for SC employees.	Increasing in COVID-19	Negative
3.	The costs of COVID-19 tests for SC employees. (Normal - Fast)	Increasing in COVID-19	Negative
4.	The costs of educating for healthcare for SC employees.	Increasing in COVID-19	Negative
5.	The costs of the vaccine and vaccination on SC employees.	Increasing in COVID-19	Negative
6.	Creating a barrier between infectious and non-infectious waste affects the cost.	Increasing in COVID-19	Negative
7.	CO_2 emissions and industrial activities.	Reducing in COVID-19	Positive
8.	CO_2 emissions and delivering activities.	Reducing in COVID-19	Positive

9.	Noise pollution.	Reducing in COVID-19	Positive
10.	In tourist destinations, ecological restoration can be accomplished by reducing the pressure on the environment.	Increasing COVID-19	Positive
11.	Wildlife and plant species protection.	Increasing COVID-19	Positive
12.	Areas that are densely populated should be reduced.	Increasing COVID-19	Positive
13.	Improved technological and scientific discovery (medical advancement).	Increasing COVID-19	Positive
14.	Research centers, IT parks, and consulting services are growing and developing.	Increasing COVID-19	Positive
15.	Increase medical waste.	Increasing COVID-19	Positive
16.	PPE waste disposal (Plastic Waste-Soil and Water pollution).	Increasing COVID-19	Negative
17.	Infectious waste.	Increasing COVID-19	Negative
18.	Education to the society for healthcare.	Increasing COVID-19	Negative
19.	A variety of job opportunities is provided (In connection with COVID).	Increasing COVID-19	Positive
20.	Amount of lost days on average.	Increasing COVID-19 condition	Positive
21.	The number of employees' health is damaged.	Increasing COVID-19	Negative

References of indicators: [54,75,113,121,11,28,114, 150,89,18,29 and this study].

6. An Analysis of the Managerial Implications and Practical Applications

The results of this investigation can provide beneficial policies for planning in disasters, principally in COVID-19, and help relevant managers to increase the sustainability of their chain by considering COVID-19 in each link of the SC, so the suggestions based on the research for other researchers and managers of industries and companies, we give a summary of it as follows:

A. Supply chain managers should have accurate estimates of costs and improve economic performance during the outbreak of the Coronavirus by considering health costs that have been neglected in the research that has been done so far in their chain.

B. Managers should pay attention to the psychological impact on employees, which is one of the most important social aspects of the SC. Managers should make accurate estimates and by taking into account the psychological damage caused by COVID-19, they should prevent their employees from suffering from mental illnesses and improve the performance of the social processes of the SC during the epidemic. Moreover, considering these damages, managers should take into account these damages during the spread of COVID-19. To give moral support to employees involved in the chain to strengthen their morale and even financial incentives (loans, facilities, living aid packages, etc).

C. Managers should have the potential ability to replace their workers in emergencies and disasters caused by COVID-19 to cover the lack of employees in these conditions with careful management of the gap caused by the coronavirus.
D. The proposed model provides managers to choose wisely and calculate the balance between costs and environmental impacts, especially greenhouse gas emissions, and control bad social impacts on the SC.
D. The design of the recovery network within this SCLSC can reduce the produced waste and optimize the components of the total cost, and with positive effects on the environment, it will ultimately help the efficiency of the chain management during the COVID-19 and lockdown period.
E. To protect employees from infectious waste and waste exposure, managers should come up with new ideas and practical measures.
F. With the increase in protective and plastic wastes (masks-gloves-medical wastes) during the COVID-19 period, special observation can be paid to their disposal and control in the SC cycle.

the final contribution of this investigation is to contribute to the performance of managing SC during COVID-19.

as well as lockdowns.

7. Conclusion and Results

The first step in this investigation was to review previous related works. Based on the most recent research, a CLSC was established. It is made up of suppliers, factories, CDs, RLs, and customers. A mathematical model was proposed for SCLSCN during COVID-19. Based on the MOMIP problem model, the main objectives are to minimize the overall cost, the bad environmental impacts, and the bad social impacts. The MOMIP was solved and the Pareto front has been created by the improved augmented weighted sum method in the LINGO software. During pandemics and lockdowns, the model can illustrate a balance between total costs, and environmental and social factors. Specifically, two cost structures are detailed in this model, it consists of a cost for an ordinary care facility without considering Coronavirus, a cost for an ordinary care facility that considers Coronavirus, including the cost of disinfectant and sanitizers, personal protective equipment, COVID-19 tests, COVID-19 education, medication, vaccine, and vaccination. There are two categories of environmental effects related to COVID-19: The COVID-19 program has positive effects on the environment (reduced CO_2 emissions, reduced noise pollution, ecological restoration, protecting species of flora and fauna, and reducing densely populated areas) and negative effects (more medical waste and more personal protective equipment). In this model, positive social aspects include job opportunities related to COVID-19. Considering the COVID-19 damages, the average number of lost days is the negative social aspect of this model. As a next step, a case study and numerical computations have been utilized to validate the presented model. The designed mathematical model was used to solve numerous examples, demonstrating its ability to find logical solutions in a wide variety of situations. Calculation of the optimization value with different weights is done, as well as the sensitivity analysis of Wi (weights). This model was solved using LINGO 19.0 software. The investigation presents a SCLSCN model during the epidemic.

These are some of the key findings of this paper in summary:

i. An applied mathematical model of SSC shows better the consequences between economic, environmental, and social aspects of COVID-19.
ii. The SC will be hygienic and responsible throughout COVID-19.
iii. Identified new sustainability aspects for COVID-19 outbreaks and lockdowns.
iv. COVID-19 and lockdowns have negative and positive effects on three aspects of sustainability.

8. Limitations and Future Scope of Research

8.1 Research limitations

Among the limiting cases of this research that exist:

a) **There are very few scientific resources, statistics, or information available for this field:** The lack of books, papers, statistics, and databases makes it difficult for researchers to conduct research in this field. Several research services are lacking, which contributes to this problem. Currently, there are only a few limited scientific sources on this subject that are directly related.
b) **Lack of similar work in this field:** Although the researcher did his best, he was unable to locate research directly addressing this matter. By studying the background of the research, we find that no paper has discussed the hygienic supply chain or the use of hygienic costs, or modeling and presenting a formula for measuring the impacts of COVID-19 on social dimensions, which may confuse the beginning of the research.
c) **Budget limitations for the work:** Each stage of research requires financial expenditures, and student research isn't an exception due to the conditions of the researcher. Budgets should be restricted to ensure the effectiveness and advancement of research. Even though the research has been conducted in Iran, we do not know how well it is coordinated with other countries. To solve this problem, we utilized different research sources around the world, used their statistical sources, and standardized the research to make it more relevant to the real world. The investigation has been conducted cross-sectionally and is highly dependent on the conditions of the COVID-19 outbreak.
d) **Limitation of information collection:** For the reasons explained above, we could only collect information from a real company.
e) As a result of the computational model's complexity, which increases the time to solve, it is possible to use meta-heuristic algorithms for very large dimensions of the problem.

8.2 Suggestions for future research

Now that we have described the limitations of the research, we will state the methods to overcome these limitations in future studies. There are several recommendations for conducting future research:

1. In light of the model with other concepts such as multi-product and multi-period chains and solutions with innovative methods and other new solution ideas.
2. It is suggested to consider some parameters, such as demand or returned with uncertainty approach to improve the current model.
3. The effect of mortality and reduction of manpower and the impact of COVID-19 disease on reducing the activity and productivity of the labor force creates a shock on the SC. It is recommended that future researchers investigate these factors with a more direct impact on employment than the effects of the shock.
4. Considering other indicators to complete the social and economic factors, for example, the satisfaction of the people involved in the SC and economic development, etc.

References

[1] Abbasi Sina, Maryam Daneshmand-Mehr, Armin Ghane Kanafi. "Designing sustainable recovery network of end-of-life product during the COVID-19 pandemic: A real and applied case study." Discrete Dynamics in Nature and Society 2022 (2022).

[2] Abbasi, Sina, Maryam Daneshmand-Mehr, Armin Ghane Kanafi. "The sustainable supply chain of CO_2 emissions during the coronavirus disease (COVID-19) pandemic." Journal of Industrial Engineering International 17.4 (2021): 83-108.

[3] Abbasi, Sina, Maryam Daneshmand-Mehr, Armin Ghane Kanafi. "Green Closed-Loop Supply Chain Network Design During the Coronavirus (COVID-19) Pandemic: a Case Study in the Iranian Automotive Industry." Environmental Modeling & Assessment (2022): 1-35.

[4] Abbasi, Sina, et al. "Performance Measurement of the Sustainable Supply Chain During the COVID-19 Pandemic: A real-life case study." Foundations of Computing and Decision Sciences 47.4: 327-358.

[5] Ahmad, Firoz, et al. "A multi-objective model for optimizing the socio-economic performance of a pharmaceutical supply chain." Socio-Economic Planning Sciences 79 (2022): 101126.

[6] Akbari-Kasgari, Maryam, et al. "Designing a resilient and sustainable closed-loop supply chain network in copper industry." Clean Technologies and Environmental Policy (2022): 1-28.

[7] Al-Othman, Wafa BE, et al. "Supply chain optimization of petroleum organization under uncertainty in market demands and prices." European Journal of Operational Research 189.3, (2008): 822-840.

[8] Alshamsi, A., Diabat, A, (2015). A reverse logistics network design. J. Manuf. Syst. Beamon, B.M., 1999. Designing the green supply chain. Logist. Inf. Manag. 12 (4), 332e342.

[9] Alumur, Sibel A., et al. "Multi-period reverse logistics network design." European Journal of Operational Research 220.1 (2012): 67-78.

[10] Anser, Muhammad Khalid, et al. "Does COVID-19 pandemic disrupt sustainable supply chain process? Covering some new global facts." Environmental Science and Pollution Research 28.42 (2021): 59792-59804.

[11] Anser, Muhammad Khalid, et al. "The impacts of COVID-19 measures on global environment and fertility rate: double coincidence." Air Quality, Atmosphere & Health 13.9 (2020): 1083-1092.

[12] Arampantzi, Christina, Ioannis Minis. "A new model for designing sustainable supply chain networks and its application to a global manufacturer." Journal of Cleaner Production 156 (2017): 276-292.

[13] Asadia, Farzaneh, Milad Abolghasemianb. "Review Coordination of Advertising Policy and Its Effect on Competition Between Retailer and Manufacture in the Supply Chain." Computational Research Progress in Applied Science and Engineering 4.3 (2018): 62-66.

[14] Awasthi, Anjali, Satyaveer S. Chauhan, Hichem Omrani. "Application of fuzzy TOPSIS in evaluating sustainable transportation systems." Expert systems with Applications 38.10, (2011): 12270-12280.

[15] Azadi, Majid, et al. "A new fuzzy DEA model for evaluation of efficiency and effectiveness of suppliers in sustainable supply chain management context." Computers & Operations Research 54 (2015): 274-285.

[16] Baral, Manish Mohan, Rajesh Kumar Singh, Yiğit Kazançoğlu. "Analysis of factors impacting survivability of sustainable supply chain during COVID-19 pandemic: an empirical study in the context of SMEs." The International Journal of Logistics Management (2021).

[17] Barbieri, Paolo, et al. "What can we learn about reshoring after Covid-19?" Operations Management Research 13.3 (2020): 131-136.

[18] Barreiro-Gen, Maria, Rodrigo Lozano, Afnan Zafar. "Changes in sustainability priorities in Organisations due to the COVID-19 outbreak: averting environmental rebound effects on society." Sustainability 12.12 (2020): 5031.

[19] Barzinpour, Farnaz, Peyman Taki. "A dual-channel network design model in a green supply chain considering pricing and transportation mode choice." Journal of Intelligent Manufacturing 29.7 (2018): 1465-1483.

[20] Bashir, Muhammad Farhan, et al. "Environmental pollution and COVID-19 outbreak: insights from Germany." Air Quality, Atmosphere & Health 13.11 (2020): 1385-1394.

[21] Bimpizas-Pinis, Meletios, et al. "Additives in the food supply chain: Environmental assessment and circular economy implications." Environmental and Sustainability Indicators 14, (2022): 100172.

[22] Broomandi, Parya, et al. "Impact of COVID-19 event on the air quality in Iran." Aerosol and Air Quality Research 20.8 (2020): 1793-1804.

[23] Cardona-Valdés, Yajaira, Ada Álvarez, Deniz Ozdemir. "A bi-objective supply chain design problem with uncertainty." Transportation Research Part C: Emerging Technologies 19.5 (2011): 821-832.

[24] Che, Zhen-Hua, et al. "A Supplier Selection Model for Product Design Changes." International Journal of Electronic Business Management 8.1 (2010).

[25] Chen, Chao, Guoqing Zhang, Yangsheng Xia. "Remanufacturing network design for dual-channel closed-loop supply chain." Procedia CIRP 83 (2019): 479-484.

[26] Chen, Jingze, Hongfeng Wang, Yaping Fu. "A multi-stage supply chain disruption mitigation strategy considering product life cycle during COVID-19." Environmental Science and Pollution Research, (2022): 1-15.

[27] Chen, Shengyong, et al. "Modeling of biological intelligence for SCM system optimization." Computational and Mathematical Methods in Medicine 2012 (2012)..

[28] Cheval, Sorin, et al. "Observed and potential impacts of the COVID-19 pandemic on the environment." International journal of environmental research and public health 17.11 (2020): 4140.

[29] Chiu, Chui-Yu, Chen-Yang Cheng, Ting-Ying Wu. "Integrated Operational Model of Green Closed-Loop Supply Chain." Sustainability 13.11 (2021): 6041.

[30] Free, Clinton, Angela Hecimovic. "Global supply chains after COVID-19: the end of the road for neoliberal globalisation?" Accounting, Auditing & Accountability Journal (2021).

[31] Das, Debashree, et al. "Building supply chain resilience in the era of COVID-19: An AHP-DEMATEL approach." Operations Management Research 15.1 (2022): 249-267.

[32] de Sousa Jabbour, Ana Beatriz Lopes, et al. "Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends." Modern Supply Chain Research and Applications (2020).

[33] Devika, Kannan, Ahmad Jafarian, and Vahid Nourbakhsh. "Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques." European Journal of Operational Research 235.3 (2014): 594-615.

[34] Diabat, Ali, Tarek Abdallah, Andreas Henschel. "A closed-loop location-inventory problem with spare parts consideration." Computers & Operations Research 54 (2015): 245-256.

[35] Edward, Rumila. "An overview of the rapid test situation for COVID-19 diagnosis in the EU/EEA." (2020).

[36] Eskandarpour, Majid, et al. "Sustainable supply chain network design: An optimization-oriented review." Omega 54 (2015): 11-32.

[37] Fakhrzad, Mohammad-Bagher, Reza Lotfi. "Green vendor managed inventory with backorder in two echelon supply chain with epsilon-constraint and NSGA-II approach." Journal of industrial engineering research in production systems 5.11,(2018): 193-209.

[38] Farooq, Muhammad Umar, et al. "Supply chain operations management in pandemics: a state-of-the-art review inspired by COVID-19." Sustainability 13.5,(2021): 2504..

[39] Fasihi, Maedeh, et al. "Developing a bi-objective mathematical model to design the fish closed-loop supply chain." International Journal of Engineering 34.5 (2021): 1257-1268.

[40] Fattahi, Mohammad, Kannan Govindan. "A multi-stage stochastic program for the sustainable design of biofuel supply chain networks under biomass supply uncertainty and disruption risk: A real-life case study." Transportation Research Part E: Logistics and Transportation Review 118, (2018): 534-567.

[41] Feitó-Cespón, Michael, et al. "Redesign of a sustainable reverse supply chain under uncertainty: A case study." Journal of Cleaner Production 151, (2017): 206-217.

[42] Ferretti, Ivan, et al. "Greening the aluminium supply chain." International Journal of Production Economics 108.1-2 (2007): 236-245.

[43] Franca, Rodrigo B., et al. "Multi-objective stochastic supply chain modeling to evaluate tradeoffs between profit and quality." International journal of production economics 127.2, (2010): 292-299.

[44] Garai, Arindam, Biswajit Sarkar. "Economically independent reverse logistics of customer-centric closed-loop supply chain for herbal medicines and biofuel." Journal of Cleaner Production 334 (2022): 129977.

[45] Garai, Arindam, et al. "Cost-effective subsidy policy for growers and biofuels-plants in closed-loop supply chain of herbs and herbal medicines: An interactive bi-objective optimization in T-environment." Applied Soft Computing 100, (2021): 106949.

[46] Gawusu, Sidique, et al. "The dynamics of green supply chain management within the framework of renewable energy." International Journal of Energy Research 46.2 (2022): 684-711.

[47] Ghane-Kanafi, A., E. Khorram. "A new scalarization method for finding the efficient frontier in non-convex multi-objective problems." Applied Mathematical Modelling 39.23-24 (2015): 7483-7498.

[48] Ghasemi, Peiman, et al. "A bi-level mathematical model for logistic management considering the evolutionary game with environmental feedbacks." The international journal of logistics management, (2021).

[49] Goli, Alireza, Erfan Babaee Tirkolaee, Gerhard-Wilhelm Weber. "A perishable product sustainable supply chain network design problem with lead time and customer satisfaction using a hybrid whale-genetic algorithm." Logistics operations

and management for recycling and reuse. Springer, Berlin, Heidelberg, (2020). 99-124.

[50] Golini, Ruggero, Matteo Giacomo Maria Kalchschmidt. "Sustainability in the food supply chain: Evidences from the Italian beef industry." 22th Annual POMS Conference. (2011).

[51] Golpîra, Hêriş, Ahvan Javanmardan. "Robust optimization of sustainable closed-loop supply chain considering carbon emission schemes." Sustainable Production and Consumption 30 (2022): 640-656.

[52] Goodarzian, Fariba, et al. "An integrated sustainable medical supply chain network during COVID-19." Engineering Applications of Artificial Intelligence 100 (2021): 104188.

[53] Govindan, Kannan, Ahmad Jafarian, Vahid Nourbakhsh. "Designing a sustainable supply chain network integrated with vehicle routing: A comparison of hybrid swarm intelligence metaheuristics." Computers & Operations Research 110 (2019): 220-235.

[54] Güner, Hatice Rahmet, İmran Hasanoğlu, Firdevs Aktaş. "COVID-19: Prevention and control measures in community." Turkish Journal of medical sciences 50.9 (2020): 571-577.

[55] Hajiaghaei-Keshteli, Mostafa, Amir Mohammad Fathollahi Fard. "Sustainable closed-loop supply chain network design with discount supposition." Neural computing and applications 31.9 (2019): 5343-5377.

[56] Harmooshi, Narges Nazari, Kiarash Shirbandi, Fakher Rahim. "Environmental concern regarding the effect of humidity and temperature on 2019-nCoV survival: fact or fiction." Environmental Science and Pollution Research 27.29 (2020): 36027-36036.

[57] Hobbs, Jill E. "Food supply chains during the COVID-19 pandemic." Canadian Journal of Agricultural Economics/Revue comedienne d'agroeconomie 68.2 (2020): 171-176.

[58] Holland, Michael, Debra J. Zaloga, Charles S. Friderici. "COVID-19 Personal Protective Equipment (PPE) for the emergency physician." Visual journal of emergency medicine 19 (2020): 100740.

[59] Huge-Brodin, Maria, Edward Sweeney, Pietro Evangelista. "Environmental alignment between logistics service providers and shippers–a supply chain perspective." The International Journal of Logistics Management (2020).

[60] Hung, AY Hoekstra PQ. "Virtual water trade a quantification of virtual water flows between nations in relation to international crop trade." (2002).

[61] Illahi, Ubaid, Mohammad Shafi Mir. "Maintaining efficient logistics and supply chain management operations during and after coronavirus (COVID-19) pandemic: Learning from the past experiences." Environment, Development and Sustainability 23.8 (2021): 11157-11178.

[62] Ivanov, Dmitry, Ajay Das. "Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: A research note." International Journal of Integrated Supply Management 13.1 (2020): 90-102.

[63] Ivanov, Dmitry, Alexandre Dolgui. "Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak." International Journal of Production Research 58.10 (2020): 2904-2915.

[64] Ivanov, Dmitry. "Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case." Transportation Research Part E: Logistics and Transportation Review 136 (2020): 101922.

[65] Ivanov, Dmitry, Ajay Das. "Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: A research note." International Journal of Integrated Supply Management 13.1 (2020): 90-102.

[66] Jahangiri, Sh, et al. "Simulation-based optimization: analysis of the emergency department resources under COVID-19 conditions." International journal of industrial and systems engineering 1.1 (2021): 1-10.

[67] Jahangiri, Shahla, et al. "Ranking of key resources in the humanitarian supply chain in the emergency department of Iranian hospital: a real case study in COVID-19 conditions." Journal of applied research on industrial engineering 8. Special Issue (2021): 1-10.

[68] Jamshidi, Rasoul, SMT Fatemi Ghomi, Behrooz Karimi. "Multi-objective green supply chain optimization with a new hybrid memetic algorithm using the Taguchi method." Scientia Iranica 19.6 (2012): 1876-1886.

[69] Kalyanmoy, D. "Multi-Objective Optimization Using Evolutionary Algorithms John Wiley & Sons.", (2001).

[70] Kampf, Günter, et al. "Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents." Journal of hospital infection 104.3 (2020): 246-251.

[71] Kannan, Devika, et al. "A carbon footprint based reverse logistics network design model." Resources, conservation and recycling 67 (2012): 75-79.

[72] Karmaker, Chitra Lekha, et al. "Improving supply chain sustainability in the context of COVID-19 pandemic in an emerging economy: Exploring drivers using an integrated model." Sustainable production and consumption 26 (2021): 411-427.

[73] Kazancoglu, Yigit, et al. "A Green Dual-Channel Closed-Loop Supply Chain Network Design Model." Journal of Cleaner Production 332 (2022): 130062.

[74] Khorshidvand, Behrooz, et al. "A hybrid modeling approach for green and sustainable closed-loop supply chain considering price, advertisement and uncertain demands." Computers & Industrial Engineering 157 (2021): 107326.

[75] Klemeš, Jiří Jaromír, Yee Van Fan, Peng Jiang. "The energy and environmental footprints of COVID-19 fighting measures–PPE, disinfection, supply chains." Energy 211 (2020): 118701.

[76] Končar, Jelena, et al. "Setbacks to IoT implementation in the function of FMCG supply chain sustainability during COVID-19 pandemic." Sustainability 12.18 (2020): 7391.

[77] Laguir, Issam, et al. "Performance effects of analytics capability, disruption orientation, and resilience in the supply chain under environmental uncertainty." Annals of Operations Research (2022): 1-25.

[78] Lang, Lingling, Zheng Liu, Bin Hu. "Optimization decision of cooperative emission reduction of clothing supply chain based on carbon tax." Journal of Physics: Conference Series. Vol. 1790. No. 1. IOP Publishing, (2021).

[79] Li, Jing, Ying Fang, Jianming Yang. "Minimizing carbon emissions of the rice supply chain considering the size of deep tillage lands." Sustainable Production and Consumption 29 (2022): 744-760.

[80] Li, Xingyu, et al. "Mathematical model of the feedback between global supply chain disruption and COVID-19 dynamics." Scientific Reports 11.1 (2021): 1-15.

[81] Li, Xueying, Ying Peng, Jing Zhang. "A mathematical/physics carbon emission reduction strategy for building supply chain network based on carbon tax policy." Open Physics 15.1 (2017): 97-107.

[82] Litman, Todd, David Burwell. "Issues in sustainable transportation." International Journal of Global Environmental Issues 6.4 (2006): 331-347.

[83] Liu, Kanying, et al. "Optimal strategies of green product supply chains based on behaviour-based pricing." Journal of Cleaner Production 335 (2022): 130288.

[84] Liu, Liwen, et al. "Collection effort and reverse channel choices in a closed-loop supply chain." Journal of Cleaner Production 144 (2017): 492-500.

[85] Lotfi, Reza, et al. "A robust optimization model for sustainable and resilient closed-loop supply chain network design considering conditional value at risk." Numerical algebra, control & optimization 11.2 (2021): 221.

[86] Lotfi, Reza, et al. "Robust optimization of risk-aware, resilient and sustainable closed-loop supply chain network design with Lagrange relaxation and fix-and-optimize." International Journal of Logistics Research and Applications (2021): 1-41.

[87] Mahdiraji, Hannan Amoozad, et al. "A novel time, cost, quality and risk tradeoff model with a knowledge-based hesitant fuzzy information: An R&D project application." Technological Forecasting and Social Change 172 (2021): 121068.

[88] Mallidis, Ioannis, Rommert Dekker, Dimitrios Vlachos. "The impact of greening on supply chain design and cost: a case for a developing region." Journal of Transport Geography 22, (2012): 118-128.

[89] Malliet, Paul, et al. "Assessing short-term and long-term economic and environmental effects of the COVID-19 crisis in France." Environmental and Resource Economics 76.4 (2020): 867-883.

[90] Martí, Joana M. Comas, Jean-Sébastien Tancrez, Ralf W. Seifert. "Carbon footprint and responsiveness trade-offs in supply chain network design." International Journal of Production Economics 166 (2015): 129-142.

[91] Mastrocinque, Ernesto, et al. "A multi-objective optimization for supply chain network using the bees' algorithm." International Journal of Engineering Business Management 5 (2013): 38.

[92] Matthias Ehrgott, Multicriteria Optimization, spring berlin. Heidelberg, printed in Germany. (2005)., ISBN3-54-21398-8

[93] Mayanti, Bening, Petri Helo. "Closed-loop supply chain potential of agricultural plastic waste: Economic and environmental assessment of bale wrap waste recycling in Finland." International Journal of Production Economics 244 (2022): 108347.

[94] Michael. Emmerich, Andre H. Deutz. A tutorial on multi-objective optimization: fundamentals and evolutionary methods. Natural Computing, (2018). 17:585–609

[95] Mohammed, Fareeduddin, et al. "Multi-period planning of closed-loop supply chain with carbon policies under uncertainty." Transportation Research Part D: Transport and Environment 51 (2017): 146-172.

[96] Mohebalizadehgashti, Fatemeh, Hossein Zolfagharinia, Saman Hassanzadeh Amin. "Designing a green meat supply chain network: A multi-objective approach." International Journal of Production Economics 219 (2020): 312-327.

[97] Moncayo-Martínez, Luis A., David Z. Zhang. "Multi-objective ant colony optimisation: A meta-heuristic approach to supply chain design." International Journal of Production Economics 131.1 (2011): 407-420.

[98] Moosavi, Javid, Seyedmohsen Hosseini. "Simulation-based assessment of supply chain resilience with consideration of recovery strategies in the COVID-19 pandemic context." Computers & Industrial Engineering 160 (2021): 107593.

[99] Mosallanezhad, Behzad, et al. "Disaster relief supply chain design for personal protection equipment during the COVID-19 pandemic." Applied Soft Computing 112 (2021): 107809.

[100] Mosallanezhad, Behzad, Mostafa Hajiaghaei-Keshteli, Chefi Triki. "Shrimp closed-loop supply chain network design." Soft Computing 25.11 (2021): 7399-7422.

[101] Muscogiuri, Giovanna, et al. "Commentary: obesity: the "Achilles heel" for COVID-19?." Metabolism-Clinical and Experimental 108 (2020).

[102] Myllyvirta. Coronavirus has temporarily reduced China's CO2 emissions by a quarter. Carbon Brief. Retrieved, from https://www.carbonbrief.org/analysis-coronavirus-has-tempo rarily-reduced-chinas- CO2 -emissions-by-a-quarter (2020).

[103] Nandi, Santosh, et al. "Redesigning supply chains using blockchain-enabled circular economy and COVID-19 experiences." Sustainable Production and Consumption 27 (2021): 10-22.

[104] Nayal, Kirti, et al. "Exploring the role of artificial intelligence in managing agricultural supply chain risk to counter the impacts of the COVID-19 pandemic." The International Journal of Logistics Management (2021).

[105] Nayeri, Sina, et al. "Multi-objective fuzzy robust optimization approach to sustainable closed-loop supply chain network design." Computers & Industrial Engineering 148 (2020): 106716.

[106] Özkır, Vildan, Hüseyin Başlıgil. "Multi-objective optimization of closed-loop supply chains in uncertain environment." Journal of Cleaner Production 41 (2013): 114-125.

[107] Özkır, Vildan, Hüseyin Başlıgil. "Multi-objective optimization of closed-loop supply chains in uncertain environment." Journal of Cleaner Production 41 (2013): 114-125.

[108] Pishvaee, Mir Saman, Masoud Rabbani, and Seyed Ali Torabi. "A robust optimization approach to closed-loop supply chain network design under uncertainty." Applied mathematical modelling 35.2 (2011): 637-649.

[109] Pishvaee, Mir Saman, and Jafar Razmi. "Environmental supply chain network design using multi-objective fuzzy mathematical programming." Applied Mathematical Modelling 36.8 (2012): 3433-3446.

[110] Pozo, Carlos, et al. "On the use of Principal Component Analysis for reducing the number of environmental objectives in multi-objective optimization: Application to the design of chemical supply chains." Chemical Engineering Science 69.1 (2012): 146-158.

[111] Raj, Alok, et al. "Supply chain management during and post-COVID-19 pandemic: Mitigation strategies and practical lessons learned." Journal of business research 142 (2022): 1125-1139.

[112] Rowan, Neil J., John G. Laffey. "Challenges and solutions for addressing critical shortage of supply chain for personal and protective equipment (PPE) arising from Coronavirus disease (COVID19) pandemic–Case study from the Republic of Ireland." Science of the Total Environment 725 (2020): 138532.

[113] Rume, Tanjena, SM Didar-Ul Islam. "Environmental effects of COVID-19 pandemic and potential strategies of sustainability." Heliyon 6.9 (2020): e04965.

[114] Saadat, Saeida, Deepak Rawtani, Chaudhery Mustansar Hussain. "Environmental perspective of COVID-19." Science of the Total environment 728 (2020): 138870.

[115] Sabio, Nagore, et al. "Holistic minimization of the life cycle environmental impact of hydrogen infrastructures using multi-objective optimization and principal component analysis." International journal of hydrogen energy 37.6 (2012): 5385-5405.

[116] Sabio, Nagore, et al. "Strategic planning with risk control of hydrogen supply chains for vehicle use under uncertainty in operating costs: a case study of Spain." International journal of hydrogen energy 35.13 (2010): 6836-6852.

[117] Salehi-Amiri, Amirhossein, et al. "Designing a sustainable closed-loop supply chain network for walnut industry." Renewable and Sustainable Energy Reviews 141 (2021): 110821.

[118] Salema, Maria Isabel Gomes, Ana Paula Barbosa Póvoa, Augusto Q. Novais. "A strategic and tactical model for closed-loop supply chains." OR spectrum 31.3 (2009): 573-599.

[119] Salema, Maria Isabel Gomes, Ana Paula Barbosa-Povoa, Augusto Q. Novais. "An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty." European journal of operational research 179.3 (2007): 1063-1077.

[120] SanJuan-Reyes, Sindy, Leobardo Manuel Gómez-Oliván, Hariz Islas-Flores. "COVID-19 in the environment." Chemosphere 263 (2021): 127973.

[121] Selvaranjan, Kajanan, et al. "Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions." Environmental Challenges 3 (2021): 100039.

[122] Shahed, Kazi Safowan, et al. "A supply chain disruption risk mitigation model to manage COVID-19 pandemic risk." Environmental Science and Pollution Research (2021): 1-16.

[123] Shahedi, Alireza, et al. "A stochastic multi-objective model for a sustainable closed-loop supply chain network design in the automotive industry." Process Integration and Optimization for Sustainability 6.1 (2022): 189-209.

[124] Sharma, Manu, et al. "Developing a framework for enhancing survivability of sustainable supply chains during and post-COVID-19 pandemic." International Journal of Logistics Research and Applications 25.4-5 (2022): 433-453.

[125] Sharma, Hari Bhakta, et al. "Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic." Resources, conservation and recycling 162 (2020): 105052.

[126] Sheu, Jiuh-Biing, Yi-Hwa Chou, Chun-Chia Hu. "An integrated logistics operational model for green-supply chain management." Transportation Research Part E: Logistics and Transportation Review 41.4 (2005): 287-313.

[127] Shirazi, Hossein, Reza Kia, Peiman Ghasemi. "Ranking of hospitals in the case of COVID-19 outbreak: A new integrated approach using patient satisfaction criteria." International Journal of Healthcare Management 13.4 (2020): 312-324.

[128] Shirazi, Hossein, Reza Kia, Peiman Ghasemi. "A stochastic bi-objective simulation–optimization model for plasma supply chain in case of COVID-19 outbreak." Applied Soft Computing 112 (2021): 107725.

[129] Sodhi, ManMohan S., Christopher S. Tang. "Supply chain management for extreme conditions: research opportunities." Journal of Supply Chain Management 57.1 (2021): 7-16.

[130] Soleimani, Hamed, et al. "Fuzzy multi-objective sustainable and green closed-loop supply chain network design." Computers & industrial engineering 109 (2017): 191-203.

[131] Song, Junnian, et al. "Shared network and supply chain features for synergetic control of carbon and air pollutant emissions." Science of The Total Environment 827 (2022): 154391.

[132] Somani, Mohit, et al. "Indirect implications of COVID-19 towards sustainable environment: an investigation in Indian context." Bioresource Technology Reports 11 (2020): 100491.

[133] Thanh, Pham Tien, et al. "No one left behind: risk communication to the street vendors during COVID-19 social distancing." Library Hi Tech, (2021).

[134] Theophilus, Oluwatosin, et al. "Truck scheduling optimization at a cold-chain cross-docking terminal with product perishability considerations." Computers & Industrial Engineering 156 (2021): 107240.

[135] Tirkolaee, E. B., Goli, A., Mardani, A. (2021). A novel two-echelon hierarchical location-allocation-routing optimization for green energy-efficient logistics systems. Annals of Operations Research, 1-29.

[136] Tirkolaee, Erfan Babaee, et al. "Designing a sustainable closed-loop supply chain network of face masks during the COVID-19 pandemic: Pareto-based algorithms." Journal of Cleaner Production 333 (2022): 130056

[137] Tirkolaee, Erfan Babaee, et al. "A novel model for sustainable waste collection arc routing problem: Pareto-based algorithms." Annals of Operations Research (2022): 1-26.

[138] Tsiakis, Panagiotis, Nilay Shah, Constantinos C. Pantelides. "Design of multi-echelon supply chain networks under demand uncertainty." Industrial & engineering chemistry research 40.16 (2001): 3585-3604.

[139] Van Doremalen, Neeltje, et al. "Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1." New England journal of medicine 382.16 (2020): 1564-1567.

[140] Waltho, Cynthia, Samir Elhedhli, Fatma Gzara. "Green supply chain network design: A review focused on policy adoption and emission quantification." International Journal of Production Economics 208 (2019): 305-318.

[141] Waltho, Cynthia. "Green Supply Chain Network Design with Emission Sensitive Demand." (2019).

[142] Wang, Fan, Xiaofan Lai, Ning Shi. "A multi-objective optimization for green supply chain network design." Decision support systems 51.2 (2011): 262-269.

[143] Xu, Lang, Chuanxu Wang, Junjie Zhao. "Decision and coordination in the dual-channel supply chain considering cap-and-trade regulation." Journal of Cleaner Production 197 (2018): 551-561.

[144] Yachai, K., Kongboon, R., Gheewala, S. H., Sampattagul, S., Carbon footprint adaptation on green supply chain and logistics of papaya in Yasothon Province using geographic information system. Journal of Cleaner Production, 281, 125214. 2021)) [145] Yang, Deyan, Dongping Song, and Cunfang Li. "Environmental responsibility decisions of a supply chain under different channel leaderships." Environmental Technology & Innovation 26 (2022): 102212.

[146] Yi, Yuyin, Jinxi Li. "Cost-sharing contracts for energy saving and emissions reduction of a supply chain under the conditions of government subsidies and a carbon tax." Sustainability 10.3 (2018): 895.

[147] Yu, Z., Razzaq, A., Rehman, A., Shah, A., Jameel, K., Mor, R. Disruption in global supply chain and socio-economic shocks: a lesson from COVID-19 for sustainable production and assumption. Operations Management Research, (2021). 1-16

[148] Zahedi, Ali, et al. "Utilizing IoT to design a relief supply chain network for the SARS-COV-2 pandemic." Applied Soft Computing 104 (2021): 107210.

[149] Zahiri, Behzad, Jun Zhuang, Mehrdad Mohammadi. "Toward an integrated sustainable-resilient supply chain: A pharmaceutical case study." Transportation Research Part E: Logistics and Transportation Review 103 (2017): 109-142.

[150] Zambrano-Monserrate, Manuel A., María Alejandra Ruano, Luis Sanchez-Alcalde. "Indirect effects of COVID-19 on the environment." Science of the total environment 728 (2020): 138813.

[151] Zare Mehrjerdi, Yahia, Reza Lotfi. "Development of a mathematical model for sustainable closed-loop supply chain with efficiency and resilience systematic framework." International Journal of Supply and Operations Management 6.4 (2019): 360-388.

[152] Zeballos, Luis J., et al. "Multi-period design and planning of closed-loop supply chains with uncertain supply and demand." Computers & Chemical Engineering 66 (2014): 151-164.

[153] Zhalechian, Mohammad, et al. "Sustainable design of a closed-loop location-routing-inventory supply chain network under mixed uncertainty." Transportation research part E: logistics and transportation review 89 (2016): 182-214.

[154] Zhang, Cheng-Tang, Li-Ping Liu. "Research on coordination mechanism in three-level green supply chain under non-cooperative game." Applied Mathematical Modelling 37.5 (2013): 3369-3379.

[155] Zhang, Shuzhu, et al. "Multi-objective optimization for sustainable supply chain network design considering multiple distribution channels." Expert Systems with Applications 65 (2016): 87-99.

[156] Zhang, Yue, et al. "Mapping of water footprint research: A bibliometric analysis during 2006–2015." Journal of Cleaner Production 149 (2017): 70-79.

[157] Zhang, Hong, Kuan Yang. "Multi-objective optimization for green dual-channel supply chain network design considering transportation mode selection." Supply Chain and Logistics Management: Concepts, Methodologies, Tools, and Applications. IGI Global, 2020. 382-404.

[158] Zhang, Xuemei, et al. "Extended warranty strategy and its environment impact of remanufactured supply chain." International Journal of Environmental Research and Public Health 19.3 (2022): 1526.

[159] Zhao, Huanhuan, et al. "Relation between awe and environmentalism: The role of social dominance orientation." Frontiers in psychology 9 (2018): 2367.

[160] Ziari, Matineh, Mohsen Sheikh Sajadieh. "A joint pricing and network design model for a closed-loop supply chain under disruption (glass industry)." RAIRO-Operations Research 56.1 (2022): 431-444.

Received 10.06.2022, Accepted 12.10.2022