

Performance Measurement of the Sustainable Supply Chain During the COVID-19 Pandemic: A real-life case study

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Abstract. This paper aims to introduce a framework to measure the sustainable performance of the supply chain (SC) during the COVID-19 pandemic. The SC stakeholders in this investigation are Suppliers, Production / Remanufacturing / Refurbishing Centers (Factories), Collection / Distribution Centers, Recycling / Landfill Centers, and Customers. The suggested sustainable supply chain (SSC) performance measurement included three pillars with 23 indicators. To evaluate the overall sustainability of the SC under study, a composite index has been developed that combines all the indicators to reflect the sustainability performance of the SC. Four steps are involved in creating a composite index: 1) measuring the value of indicators, 2) weighing indicators, 3) Using the normalization technique, and 4) Evaluating the overall SSC indicator. The real case in Iran is selected as an illustrative case. Our research contributions are: We suggested a novelty indicator of SSC to better show the economic, environmental, and social trade-offs during the COVID-19 pandemic and lockdowns. We have found and measured the negative and positive impacts of COVID-19 on aspects of sustainability in SC. Based on the achieved data of the real case study, a numerical example is represented to explain how to calculate the composite index. The main contribution of this paper is the development of SSC indicators during the COVID-19 epidemic.

Keywords: Sustainable Supply Chain, COVID-19 pandemic, Performance Measurement, Hierarchical additive weighting method.

1. Introduction

The supply chain (SC) worldwide continues to be affected by the challenges of the COVID-19 epidemic, including delays and disruptions. Many senior executives now see SC turmoil as the biggest threat to their companies' and economies' growth. Organizations need to

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think and manage their SC differently to ensure business continuity and growth for the future. COVID-19 causes a chaotic situation in the global SC [63]. The best way to prevent disease is a lockdown policy and reduced physical contact [75]. We should reduce the impact of environmental damage during SC activities [16]. The increasing COVID-19 also fundamentally impacts the environment, economy, and society [74]. The sustainability of SC, considers economic benefit, social benefit, and our planet, simultaneously [36]. Large-scale data collection for testing the proposed research model can be used to analyze causality and test research hypotheses. However, it ranks the determinative of new technology adoption based on expert preferences in hiring decisions, finds out which is more important in hiring decisions, and helps organizations better understand hiring scenarios [126]. The AHP, a quantitative method for multi-criteria decision-making, allows for the resolution of the issues by constructing a weighting scale regarding the priorities of determinants [50]. The AHP method has been widely used for ranking determinants [81]. Using the MCDM technique for supplier selection [33]. Considering N-retailers in SC by [59]. An overview of supply chain issues can be found in Figure 1.

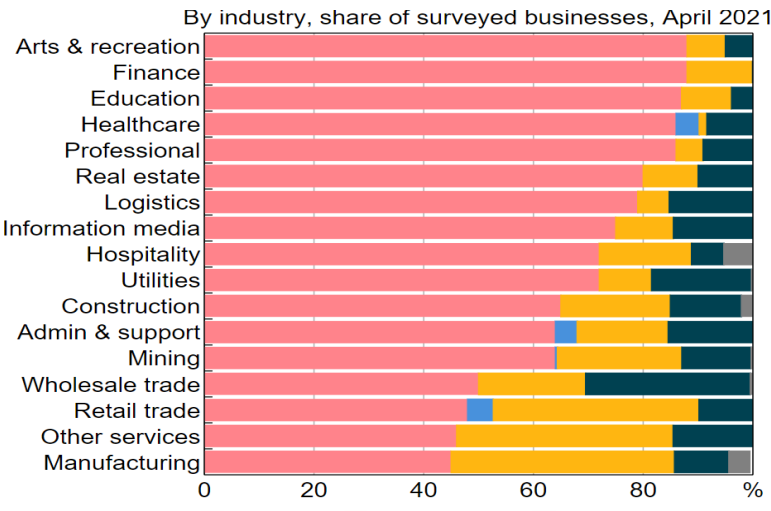


Figure 1. Reports of supply chain issues [135,26]

This paper's model has been designed to increase SC's efficiency by incorporating economic, environmental, and social performance indicators into the sustainable supply chain network design (SSCND) during the COVID-19 pandemic. The model described above is considered to provide five types of facilities:1) Suppliers,2) Factories,3) Collection / Distribution Centers,4) Customers, and 5) Recycling / Landfill Centers. Therefore, this investigation refers to measuring the sustainability of the new model with the AHP method to fill this gap in the COVID-19 condition.

2. Research background and contribution

This research background and contribution section is divided into two subsections. The first subsection, SSC performance indicators, the second subsection considers the COVID-19 pandemic in SC being studied, and the third subsection discusses the research gap and innovation.

2.1. SSC performance indicators

The global reporting initiative (GRI) creates a comprehensive sustainability reporting framework widely used worldwide to increase organizational transparency. The framework, which includes guidelines for sustainability reporting, provides principles and indicators that organizations can use to report on economic, environmental, and social performance. The main domain of the GRI concentrates on economic, environmental, and social pillars [134].

2.1.1. The economic pillar

The first pillar of the SSC has got economic aspects. The traditional network design of SC aimed to minimize costs or maximize incomes without regarding environmental issues. Now take a brief look at the work done in this area of research. Minimizing total cost for Supply chain network (SCN) [130]. Considering costs, short delivery products time, and best quality of products in SC [31]. Maximizing profit for SCN considering storage level [118]. Maximizing of profit product in SC by [128]. Minimizing the total cost of SCN during the distribution of products [117]. Maximizing profit regarding the number of inventory products [137]. Focused on costs and minimization of total time for service by [29,5]. Researched costs of SC, customer service, and capacity of echelons [48]. Investigation of for-profit and defects in SC [57].

2.1.2. The environmental pillar

The second pillar of the SSC is the protection of the environment. Raising public awareness of environmental issues has increased the desire to design an environmentally friendly SCN [104]. Researchers have recently compared green supply chain management (GSCM) [132]. Surveyed some other aspects of SC, such as carbon emissions, and fuel and energy consumption [143]. Research on water human consumption during the SC [64,144]. Investigation on noise pollution and solid and water waste during the SC [20]. Discussion about CO₂ emissions released by logistics transportation [129]. Researched for controlling CO₂ emissions during manufacturing and recycling final product [80]. Lockdowns related to COVID-19 helped to control the transmission rate of CO₂ and reduce emissions [97].

2.1.3. The social pillar

There has been an increase in interest in the social side of SSC among both universities and industry in recent years. For beef SC, three aspects of sustainability are considered [51].

Regional expansion and regional balancing expansion are two aspects of societal commitment [43,139]. In a study by Zhang et al. and Feitó Cespón et al. [144,44], customer satisfaction was also considered as a social purpose. Several studies have highlighted the importance of employee satisfaction and workplace environments [15,54]. An analysis of the sustainable pharmaceutical SC under uncertainty, focusing on social and economic factors. When designing the CLSC network, sustainability should be taken into account [52]. An analysis of the sustainability of CLSCs using a constraint-based approach [124]. Developing a CLSC that consumes water and air pollution was suggested to be sustainable and resilient [5]. Using a sustainable closed-loop supply chain network (SCLSCN) created by Nayeri et al [99]. To optimize sustainable and resilient CLSC designs, conditional values at risk are modeled [85]. A mathematical model evaluates closed-loop supply chains for robustness and efficiency [141]. With Lagrange relaxations and fix-and-optimize approaches, develop a robust model for SCLSCN [87].

2.2. Recent and COVID-19 investigations

Research on SC with considering resilience concepts during COVID-19 [67]. Researched the shortage of protective and sanitary tools during the COVID-19 disaster [112]. Study on the future impacts of the COVID-19 pandemic on SC [66]. Investigation on SC of food during the epidemic [62]. Concentrating on intertwined SCN during COVID-19 [68]. Considering the SC during and after COVID-19 [46]. Controlling a risk for managing the SC in the COVID-19 condition [123]. SCN during the COVID-19 [98]. SC strategies for the post-COVID-19 [69]. Discussion about recovery in SC during COVID-19 [101]. Designing a closed-loop supply chain network (CLSC) with considering the environmental and economic problems [116]. Researched a SC with two-echelon for perishable products [7]. Considering environmental with fuzzy approaches in SC design [42]. Research on the logistics of the SC has been done by [114]. Creating resilience for SC in COVID-19 by using the AHP [121]. A risk-aware multi-objective optimization solution for renewable energy location [83]. The pharmaceutical industry has implemented a circular supply chain management system [73]. Modeling the COVID-19 pandemic in Iran with an extended robust mathematical model [84]. An integrated decision-making framework for managing municipal plastic waste through bio-recovery [125]. Flexible and vendor-managed inventory optimization for resilience and sustainability in the health care SC [86]. To optimize biofuel supply chains based on microalgae biofuels and co-products, a mixed-integer linear programming model is proposed: a case study in Iran [142]. Using gray AHP and gray COPRAS frameworks to select cold chain logistics suppliers in Vietnam [100]. Using the SCOR Model and multi-criteria decision-making method to measure the supply chain performance of the floricultural sector [111]. Managing healthcare and pharmaceutical supply chains using multiple criteria [78]. Incorporating an application case study into the design of a sustainable recovery network of end-of-life products in response to the COVID-19 pandemic by Abbasi et al [1]. While COVID-19 was spreading, Abbasi et al implemented a sustainable supply chain to control CO₂ emissions [2].

2.3. Research gap and innovation

There are many research gaps related to the COVID-19 pandemic. To discover the research gap, we first searched between papers from 1993 to 2022. Table 1 illustrates the various aspects of the supply chain. Previous research has not considered three aspects of sustainability, and the COVID-19 pandemic simultaneously. Accordingly, the proposed paper highlights several gaps in the literature, and innovation is categorized in some of the following ways:

1. We developed an indicator of SSC for the COVID-19 pandemic and lockdowns that considered SSC's economic, environmental, and social aspects.
2. We measure the performance of SSC with the AHP approach.
3. The results of the COVID-19 analysis showed both negative and positive effects on SC.
4. The proposed SSC performance measurement of the echelon.

Table 1. Different aspects of the supply chain, considering the COVID-19 pandemic

Author(s)	Reference	Year	Economic Aspects	Environmental Aspects	Social Aspects	COVID-19 Pandemic
Caruso et al	[30]	1993	*	*	*	
Berger et al	[22]	1999	*	*		
Tsiakis et al	[130]	2001	*	*		
Krikke et al	[76]	2003	*	*		
Fynes et al	[47]	2004	*	*		
Sheu et al	[128]	2005	*	*		
Salema et al	[117]	2007	*			
Sheu et al	[127]	2008	*	*		
Salema et al	[118]	2009	*			
Dehghanian & Mansour	[35]	2009	*	*	*	
Bojarski et al	[24]	2009	*	*		
Franca et al	[45]	2010	*			
Yang et al	[137]	2010	*			
Guillén-Gosálbez & Grossmann	[55]	2010	*	*		
Ramudhin et al	[108]	2010	*	*	*	
Cardona-Valdés et al	[29]	2011	*			
Pishvae et al	[106]	2011	*			
Chaabane et al	[28]	2011	*	*		
Harraz & Galal	[61]	2011	*	*	*	
Pinto-Varela et al	[103]	2011	*	*		
Mele et al	[93]	2011	*	*	*	
Ashayeri et al	[9]	2012	*	*	*	
Pishvae & Razmi	[104]	2012	*	*		
Pozo et al	[107]	2012	*	*		
Giarola et al	[49]	2012	*	*		
Pérez-Fortes et al	[102]	2012	*	*	*	

Akgul et al	[6]	2012	*	*		
Elia et al	[40]	2012	*	*		
Kannan et al	[71]	2012	*	*		
Mallidis et al	[90]	2012	*	*		
Chaabane et al	[27]	2012	*	*	*	
You et al	[138]	2012	*	*	*	
Bernardi et al	[23]	2013	*	*		
Lam et al	[79]	2013	*	*		
Bouzembrak et al	[25]	2013	*	*	*	
Sadrnia et al	[115]	2013	*	*		
Pishvaei et al	[105]	2014	*	*	*	
Baud-Lavigne et al	[19]	2014	*	*		
Devika et al	[37]	2014	*	*	*	
Mota et al	[96]	2014	*	*	*	
Marufuzzaman et al	[92]	2014	*	*		
Rezapour et al	[109]	2015	*	*		
Esfahbodi et al	[41]	2016	*	*		
Zhalechian et al	[143]	2016	*	*	*	
Mohammed et al	[94]	2017	*	*		
Zahiri et al	[139]	2017	*	*	*	
Santibanez-Gonzalez	[120]	2017	*	*		
Michael Feitó-Cespón et al	[44]	2017	*	*	*	
Arampanzi & Minis	[15]	2017	*	*	*	
Waltho et al	[132]	2018	*	*		
Allaoui et al	[11]	2018	*	*	*	
Wu & Huang	[133]	2018	*	*	*	
Doolun et al	[38]	2018	*	*		
Fattahi & Govindan	[43]	2018	*	*	*	
Govindan et al	[53]	2018	*	*	*	
Vafaenezhad et al	[131]	2019	*	*	*	
Hajiaghahi-Keshteli & Fathollahi Fard	[58]	2019	*	*	*	
Liu et al	[82]	2020	*	*		
Mohammadia et al	[95]	2020	*	*	*	
Ashraf et al	[10]	2020	*	*		
Jemai et al	[70]	2020	*	*		
Alzoubia et al	[14]	2020	*	*	*	
Kumar et al	[77]	2020	*	*	*	
Agyabeng-Mensah et al	[4]	2020	*	*		
Zhang et al	[145]	2020	*	*		
Sánchez-Flores et al	[119]	2020	*	*	*	
Sanjoy and Priyabrata	[101]	2020	*			*
Ketchen & Craighead	[72]	2020				*

Al-Mansour& Al-Ajmi	[12]	2020	*			*
Dmitry Ivanov & Ajay Das	[67]	2020				*
Dmitry Ivanov & Alexandre	[68]	2020				*
Rowan &Laffey	[112]	2020				
Handfield et al	[60]	2020				*
Jill E. Hobbs	[62]	2020				*
Rizou et al	[110]	2020		*		*
Lopes de Sousa Jabbour et al ⁴	[36]	2020			*	*
Benzidia et al	[21]	2021	*	*		*
E.Qazvinia et al	[39]	2021	*	*		
Mahjooba et al	[89]	2021	*	*		
Chen et al	[32]	2021	*	*	*	
Al-Zabidi et al	[13]	2021	*	*	*	
Yadav et al	[136]	2021	*	*	*	
Ivanov	[65]	2021				*
Luckstead et al	[88]	2021	*			*
Shahed et al	[123]	2021	*			*
Golpîra	[52]	2022	*	*	*	
Shahedi	[124]	2022	*	*	*	
Akbari-Kasgari	[5]	2022	*	*	*	
<i>Current Research</i>	-----	2022	*	*	*	*

3. Problem statement and assumptions

Sustainability is an important performance aspect that needs to be considered when designing SCs. The SSC covers three sustainability pillars (economic, environmental, and social). Therefore, SSC theoretically allows the competitiveness of all members of the SC. To the competitiveness of SCs, it is essential to evaluate SC performance first. This research aims at a holistic framework to help measure SSCs performance during the COVID-19 pandemic. These proposed indicators focus on effectiveness and efficiency in terms of performance. Efficiency is used for measuring input usage, and effectiveness is used for measuring the goals or outcomes. The SC stakeholders in this study are Suppliers (S), Production / Remanufacturing / Refurbishing Centers (Factories) (F), Collection /

⁴ This is a conceptual article without mathematic model.

Distribution Centers (CDC), Recycling / Landfill Centers (RLC), and Customers (C). The forward flow begins with the extraction of raw materials from suppliers and delivering them to the factories to produce a new product. A product is shipped along the way to meet the customer's needs. In the reverse SC, the returned products are collected and transported to the collection/distribution centers, we examine the returned products and determine if they can be remanufactured and refurbished, and then ship them to our factories, and others are sent to the recycling/landfill centers. finally, the recycled materials are returned to the beginning point of the SC. New assumptions related such as: In the SC, the COVID-19 pandemic is thoroughly examined, all customer demands were met during the emergency COVID-19 situation the returned products that need to be disposed of through the COVID-19 hygiene protocol are always successfully disposed of, and there should be a feasible distance between echelons. This study's SC diagram is shown in Figure 2.

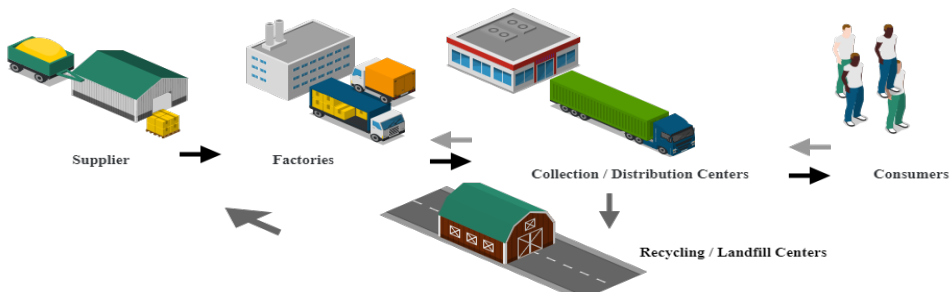


Figure 2. The SC diagram during COVID-19

3.1. Indicators for SSC during the COVID-19

In this paper, we proposed new indicators of sustainability for SC during the COVID-19 and lockdowns. The indicators for SSC in COVID-19 are shown in Table 2.

3.1.1. Hygiene costs during the COVID-19

- Disinfection costs.
- Hand sanitizer costs.
- The costs of prevention equipment (Shield-Mask-Gown-Gloves etc.).
- COVID-19 detection kits costs (Normal - Fast).
- The education and information about COVID-19 costs.
- The medicines, vaccine, and vaccination costs for COVID-19 [74,56].

3.1.2. Positive impacts of COVID-19 and lockdown on the environment

- Reducing industrial activities and CO₂ emissions during the COVID-19 pandemic and lockdowns.
- Reducing shipping activities and CO₂ emissions during the COVID-19 pandemic and lockdowns.
- Reducing noise pollution during the COVID-19 pandemic and lockdown.
- Ecological restoration by reducing pressure on tourist destinations during the COVID-19 pandemic and lockdown.
- Protection of flora and fauna species during species COVID-19 pandemic and lockdowns.
- Reduction of the densely populated area during the COVID-19 pandemic and lockdowns.
- Technological and scientific discoveries and medical advancements during the COVID-19 pandemic.
- Growth and development of IT parks, research centers, and consultancy related to the prevention and control of COVID-19 [122,8,18,34].

3.1.3. Negative impacts of COVID-19 on the environment

- Increase plastics and medical waste during the COVID-19 pandemic.
- Increasing prevention of equipment waste disposal during the COVID-19 pandemic (plastic waste-soil and water pollution) [113,3,140].

3.1.4. Positive impacts of COVID-19 and lockdown on the society

- Education to society on mental health, healthcare, prevention, and control of the COVID-19 virus.
- A variety of new job opportunities Related to COVID-19

3.1.5. Negative impacts of COVID-19 and lockdown on the society

- The average number of lost days caused by COVID-19 damages. (Psychologically destructive, mental illness, and hospitalization during the COVID-19, etc) [91,17].

Table 2. Indicators for SSC during the COVID-19

Indices	Economic	Indices	Environmental	Indices	Social
EC ₁	Fixed cost for the opening facility.	EN ₁	CO ₂ emissions during COVID-19 and look down. (Industrial activities)	SO ₁	Education to the society for healthcare, prevention, and control of COVID-19.
EC ₂	Normal variable costs.	EN ₂	CO ₂ emissions during COVID-19 and look down. (Shipping)	SO ₂	A variety of job opportunities related to COVID-19 are provided.
EC ₃	Disinfection costs.	EN ₃	Noise pollution during the COVID-19 pandemic and lockdown.	SO ₃	The average number of lost days caused by lockdown during the COVID-19 pandemic
EC ₄	Hand sanitizer costs.	EN ₄	Ecological restoration during the COVID-19 pandemic and lockdown.	SO ₄	The average number of lost days caused by COVID-19 hospitalization.
EC ₅	The costs of prevention equipment (Shield-Mask-Gown-Gloves etc).	EN ₅	Protection of species of flora and fauna during the COVID-19 pandemic and lockdown.	SO ₅	Cause adverse effects on local communities, disturbances to a sacred site or other cultural values during the COVID-19 pandemic, and lockdown.
EC ₆	The COVID-19 tests cost (Normal- Fast).	EN ₆	Densely populated area during the COVID-19 pandemic and lockdown.	—	—

EC ₇	The COVID-19 educating costs.	EN ₇	Hazardous personal protective equipment (PPE) waste during the COVID-19 pandemic.	—	—
EC ₈	The costs of the COVID-19 vaccine and vaccination.	EN ₈	Hazardous medical waste (MW) amount during the COVID-19 pandemic.	—	—
EC ₉	The cost of separation of COVID-19 and non-COVID-19 waste.	EN ₉	Hazardous COVID-19 waste.	—	—

3.2. Methodology

To measure the SC's overall sustainability, you can develop a composite index that reflects your overall assessment. A composite index is widely used for a combination of individual indicators. This composite index will show the overall SSC performance, which covers all the different performance pillars. Table 3 shows the fundamental scale of this research.

Table 3. Fundamental Scale

Definition	The numerical value (Level of preference)	Description
Equally Preferred	1	Two activities contribute equally to the objective.
Moderately Preferred	3	Experience and judgment slightly favor one activity over another.
Strongly Preferred	5	Experience and judgment strongly favor one activity over another.
Very strongly Preferred	7	An activity is favored very strongly over another.

Extremely Preferred	9	The evidence favoring one activity over another is of the highest possible order of affirmation.
Intermediate preferred values	2, 4, 6, 8	Shows intermediate values for example 8 indicates importance greater than 7 and, lower than 9. 2 is weak or slight, 4 is a moderate plus, 6 is a strong plus, and 8 is very, very strong.

There are steps to generate a composite index that will calculate overall SSC performance as follows:

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_n} \end{pmatrix}$$

$a_{ij} = w_i / w_j \quad \forall i, j. \text{ with } a_{ij} > 0, \text{ expressing}$
the degree of preference of x_i to x_j ;

(1)

calculate the indicators for measuring the actual value. Create a comparison matrix ($n \times n$) for criteria concerning the objective by using a 1-9 scale (Table 3), it is used to compare each criterion with each other criterion, one by one. The pairwise comparisons are collected into a pairwise comparison matrix. $A = (a_{ij})_{n \times n}$, structured as above.

$$(\prod_{i=1}^n x_i)^{\frac{1}{n}} = \sqrt[n]{x_1 x_2 x_3 \dots x_n}$$

(2)

Use geometric mean (GM) for calculation of the archive weights of indicators.
Positive criteria:

$$N_{ij} = \frac{r_{ij}}{r^*_j}$$

$i = 1, 2, \dots, m; j = 1, 2, \dots, n$

(3)

r^*_j is the maximum number of r in the column of j .

Negative criteria:

$$N_{ij} = \frac{r_j^{min}}{r_{ij}} \qquad i=1,2,...,m; j= 1,2,..., n \qquad (4)$$

Construct a decision (m×n) matrix: use the normalization method to convert various units of measurement to standard measurements. An illustration of the AHP-based model used to evaluate overall SSC performance during the COVID-19 pandemic is shown in Figure 3. The Evaluate Overall SSC Indicator (OSSCI) is calculated by the formula

$$\sum_j \sum_i W_j X_{ij}.$$

W_j : Weight of indicators j $j= 1,2,..., n$ (5)

X_{ij} : Normalized values ij $i=1,2,...,m; j= 1,2,..., n$ (6)

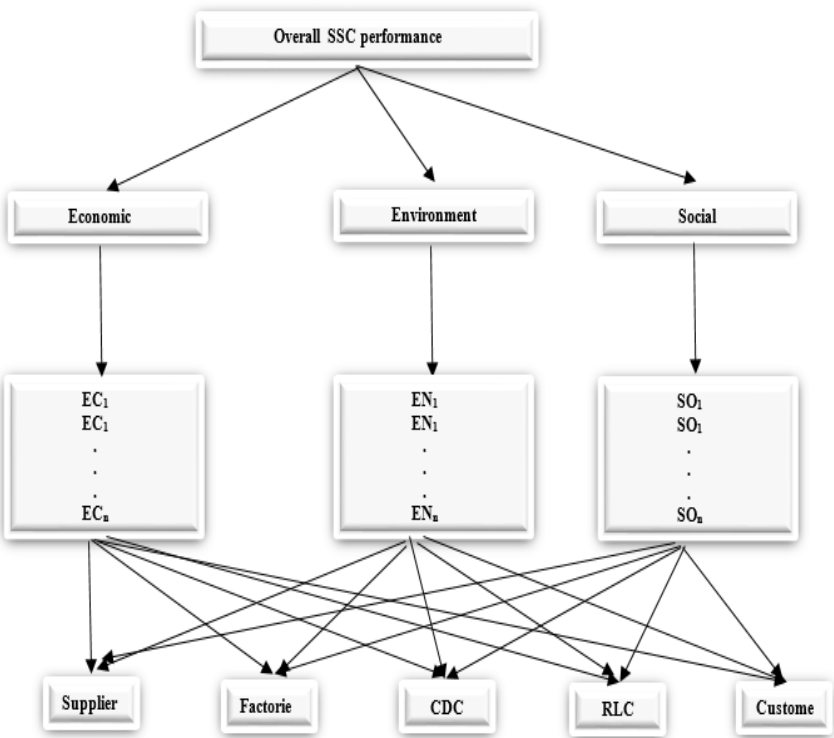


Figure 3. An AHP-based model for the evaluation of overall SSC performance during the COVID-19 pandemic

4. Numerical example (Based on real case study)

As of 19 February 2020, COVID-19 has been confirmed in Iran for the first time. We collect data from the Company’s SC. An evaluation of the model's outcomes has been conducted in a real case study. In this step, we evaluate the accuracy of the created model and the functionality of the solution method by the data for the intended case study. The economic novelty aspect of this paper is the hygienic cost. It includes disinfection and sanitizer costs, personal protective equipment (PPE) costs, COVID-19 test costs, COVID-19 education costs, and the costs of COVID-19 vaccine and vaccination costs. The novelty and positive social aspects of this model include education to society on healthcare, prevention, and control of COVID-19, and a variety of job opportunities related to COVID-19. This model's novelty negative social aspect is the average number of lost days caused by COVID-19 damages. There are two environmental novelty aspects in this study were existed about COVID-19. These are divided into two categories: Positive impacts of COVID-19 on the environment (reduce CO₂ emissions, reduce noise pollution, ecological restoration, protection of species of flora and fauna, reduction of densely populated areas, etc) and negative impacts of COVID-19 on the environment (increase medical and PPE waste). The validity and reliability of the developed model and the performance of the methods of solving the problem are evaluated through the data for the considered case study. In our work, performance measurement of SSC every component was prepared using COVID-19 impact sources of baseline data of the study area.

4.1. Calculation of economics pillars

For calculating the weights of indicators for the economics pillar, there are four indicators: fixed costs, variable costs, hygienic costs, and costs of separation of waste, as described in Table 4. Table 5 shows the steps for the calculation of the weights of the indicator by geometric mean. The weight of hygienic cost is the maximum weight of indicators for the economics pillar, with a weight of 0.479. A pairwise comparison matrix is shown in Table 4. Table 5 demonstrates the geometric mean for the economic pillar.

Table 4. Pairwise comparison matrix for economic pillar during the COVID-19 pandemic

Facility	Fixed costs	Variable costs	Hygiene costs	Costs of separation of waste
Fixed costs	1	5	1/7	1/5
Variable costs	1/5	1	1/3	1/2
Hygiene costs	7	3	1	2
Costs of separation of wastes	5	2	1/2	1

Table 5. The geometric mean for the economic pillar

Indicators	Geometric Mean	Weight
Fixed costs	$[1 \times 5 \times 1/7 \times 1/5]^{1/4} = 0.614$	0.125
Variable costs	$[1/5 \times 1 \times 1/3 \times 1/2]^{1/4} = 0.427$	0.087
Hygiene costs	$[7 \times 3 \times 1 \times 2]^{1/4} = 2.340$	0.479
Costs of separation of wastes	$[5 \times 2 \times 1/2 \times 1]^{1/4} = 1.495$	0.306
Total	4.876	1

4.2. Calculation of the environmental pillars

To calculate the weights of indicators for an environmental pillar, four indicators are CO₂ emission, industrial activity/shipping, noise level, ecological restoration, protection of species of flora and fauna, densely populated, and waste minimization, as described in Table 5. The weight of Densely populated is the maximum weight of indicators for the environmental pillar, with a weight of 0.484.

Table 6. Pairwise comparison matrix for the environment pillar during the COVID-19 pandemic

Facility	CO ₂ emission (gCO ₂ /tonne-km)	Noise level (>80 dB)	Ecological restoration	Protection of species of flora and fauna	Densely populated	Waste minimization
CO ₂ emission (gCO ₂ /tonne-km)	1	3	2	2	1/3	2
Noise level (>80 dB)	1/3	1	1/4	1/4	1/6	1/3
Ecological restoration	1/2	4	1	2	1/7	4
Protection of species of flora and fauna	1/2	4	1/2	1	1/5	3
Densely populated	3	6	7	5	1	7
Waste minimization	1/2	3	1/4	1/3	1/7	1

Table 7. The geometric mean for the environmental pillar

Indicators	Geometric Mean	Weight
CO ₂ Emission industrial activity/shipping (gCO ₂ /tonne-km)	1.414	0.169
Noise level (>80 dB)	0.324	0.038
Ecological restoration	1.147	0.137
Protection of species of flora and fauna	0.918	0.109
Densely populated	4.049	0.484
Waste minimization (PPE, COVID-19 waste and medical waste)	0.511	0.061
Total	8.363	1

Table 6 shows the steps to calculate the weights of the indicator by geometric mean. For the environmental pillar, Table 7 represents the geometric mean.

4.3. Calculation of social pillar

To calculate the weights of indicators for a social pillar, there are four indicators: education, community disturbances, job opportunities, and lost days, as described in Table 8. Table 9 shows the steps to calculate the weights of the indicator by geometric mean. The weight of education is the maximum weight of indicators for the social pillar, with a weight of 0.649.

Table 8. Pairwise comparison matrix for social pillars during the COVID-19 pandemic

Facility	Education	Communities disturbances	Employment rate (Job opportunities)	Lost days (Lockdown – Hospitalization)
Education	1	5	7	6
Communities disturbances	1/5	1	3	2

Employment rate (Job opportunities)	1/7	1/3	1	2
Lost days	1/6	1/2	1/2	1

Table 9. Geometric mean for social pillar during the COVID-19 pandemic

Indicators	Geometric Mean	Weight
Education	3.806	0.649
Communities disturbances	1.046	0.178
Employment rate (Job opportunities)	0.555	0.094
Lost days	0.451	0.0769
Total	5.858	1

Table 10. Pairwise comparison matrix of stakeholders during the COVID-19 pandemic

<i>Facility</i>	Suppliers	Factories	Collection / Distribution Centers	Recycling / Landfill Centers	Customers
Suppliers	1	1/2	2	1/3	1
Factories	2	1	2	2	2
Collection / Distribution Centers	1/2	1/2	1	1/2	1
Recycling / Landfill Centers	3	1/2	2	1	2
Customers	1	1/2	1	1/2	1

Table 8 shows the pairwise comparison matrix for social pillars during the COVID-19 pandemic. Table 9 provides the geometric mean for social pillars during the pandemic. Table 10 displays the pairwise comparison matrix of stakeholders during the pandemic.

Table 11. The normalized decision matrix of stakeholders during the COVID-19 pandemic

<i>Facility</i>	Suppliers	Factories	Collection / Distribution Centers	Recycling / Landfill Centers	Customers
Suppliers	0.333	0.5	1	0.166	0.5
Factories	0.666	1	1	1	1
Collection / Distribution Centers	0.166	0.5	0.5	0.25	0.5
Recycling / Landfill Centers	1	0.5	1	0.5	1
Customers	0.333	0.5	0.5	0.25	0.5

Based on the economic weight set previously that $W_{\text{economic}} = (0.125, 0.087, 0.479, 0.306)$

Economic indicator for suppliers	Economic indicator for factories	Economic indicator for <i>CDC</i>	Economic indicator for <i>RL</i>	Economic indicator for customers
2.49	4.65	1.91	3.98	2.076751

Based on the environmental weight set previously that $W_{\text{environmental}} = (0.169, 0.038, 0.137, 0.109, 0.484, 0.061)$.

Environmental indicator for suppliers	Environmenta l indicator for factories	Environmental indicator for <i>CDC</i>	Environmental indicator for <i>RL</i>	Environmental indicator for customers
2.49	4.65	1.91	3.99	2.07

Based on the social weight set previously that $W_{\text{social}} = (0.649, 0.178, 0.094, 0.0769)$.

Social indicator for suppliers	Social indicator for factories	Social indicator for CDC	Social indicator for RL	Social indicator for customers
2.49	4.65	1.91	3.99	2.07

The overall sustainable supply chain indicators are formulated as follows:

Overall SSC indicators =Economics indicators + Environmental indicators+ Social indicators

Table 12. Overall sustainable supply chain index during the COVID-19 pandemic

<i>Facility</i>	Suppliers	Factories	Collection / Distribution Centers	Recycling / Landfill Centers	Customers
Suppliers	0.333	0.5	1	0.166	0.5
Factories	0.666	1	1	1	1
Collection / Distribution Centers	0.166	0.5	0.5	0.25	0.5
Recycling / Landfill Centers	1	0.5	1	0.5	1
Customers	0.333	0.5	0.5	0.25	0.5

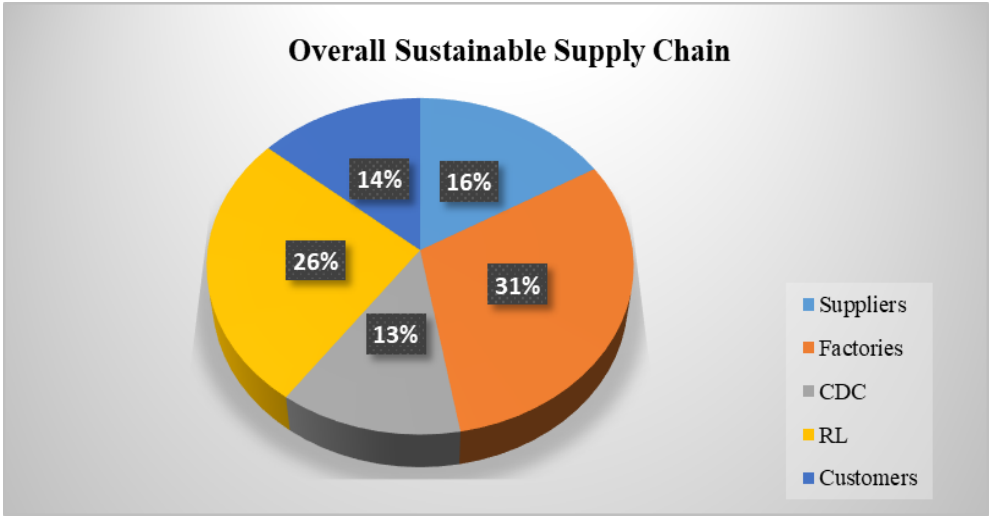


Figure 4. Overall SSC during the COVID-19 pandemic

As shown in Table 11, stakeholders made normalized decisions during the COVID-19 pandemic. In Table 12, we find an overall index of sustainable supply chains. As a result, of COVID-19, Figure 4 illustrates the overall SSC.

5. Managerial insights

The results of this study can assist the management purposefully in the COVID-19 situation and help the managers such the following:

- i. During the pandemic, managers should consider the damage COVID-19 has caused in their SC and estimate the social aspects accurately.
- ii. During COVID-19, the SC's managers should identify and address hygienic issues within their organization to get accurate estimates and improve the performance of processes.
- iii. By using the right tools and methods, managers can maintain sustainability in SC.
- iv. In emergency and disaster circumstances, managers should be able to replace their workers.
- v. A financial relief package should have been provided to the employees involved in the SC during COVID-19.
- vi. The psychological impact of COVID-19 on employees should be noted by managers.

6. Concluding remarks and perspectives

6.1. Conclusions

This study explains SSC performance, including suppliers, factories, collection/distribution centers (CDC), recycling/landfill (RL) centers, and customers. The proposed SSC performance measurement with 23 indicators according to triple stability pillars to evaluate SSC. More composite indexes have been developed to show the generality performance of CSS. There are four steps to creating a composite index: 1) Measuring the value of indicators, 2) Weighting indicators, 3) Using the normalization technique, and 4) Evaluating the overall SSC indicator. In this study, a numerical example shows how to establish a composite index using a real case study during COVID-19. The archived results suggest an overall sustainability score of 16% for suppliers, 31% for factories, 13% for CDCs, 26% for RLs, and 14% for customers, respectively. The proposed overall sustainability score may help identify critical points between SC stakeholders during the COVID-19 pandemic.

6.2. Limitations

The limitations of our work that can be addressed in future research:

We had access to data from just one real company. The pairwise comparison judgment from our expert team members had any limitations on their decisions. Lack of similar direct work in this area. Limited budget required to carry out and advance the work. The research was conducted cross-sectionally.

6.3. Recommendations

The recommendations for future work are as follows:

- a) Added other indicators for completing the three aspects of sustainability.
- b) Select several other methods for organizing and analyzing complex decisions.
- c) Compare the several methods and choose the best method for measuring.
- d) Using psychology concepts more in the mathematics model.

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