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Impact of COVID-19 on Sustainability Enablers and Evaluation of Performance Index

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Abstract

Sustainability deals with the impact of various processes and products on the economy, environment, and society. Due to the outburst of deadly coronavirus disease (COVID-19), sustainability which has three dimensions i.e., economy, environment, and social have been severely afflicted. Logistics has been stopped due to the spread of COVID-19 by which disruption in supply and demand takes place. This paper involves the study of the impact of COVID-19 on sustainability enablers. Also, the sub-attributes of sustainability enablers are studied and the performance index is calculated for pre and during COVID-19 with the help of the Graph-theoretic approach (GTA). With the help of the graph-theoretic approach (GTA), the inter-relationship between the sustainability enablers pre and during COVID-19 has been studied thereby quantitatively measuring the extent to which COVID-19 has an impact on sustainability enablers. The objective of this study is to identify a performance index by analyzing different sub-attributes of sustainability enablers. Also, digraphs are shown for the whole system and sub-systems representing inter-relationships and dependencies between various enablers and attributes to interpret the performance of the sustainability enablers before and during the time of COVID-19. This paper provides the impacts of COVID-19 on these three factors and provides the framework how to identify the performance index pre and during COVID-19. Copyright © 2022 Elsevier Ltd. All rights reserved.

1. Introduction

The outburst of coronavirus disease 2019 (COVID-19) gives an insight that the three sustainability enablers i.e., economy, environment and social are connected. The balanced integration of economy, environment and social plays an important role to attain overall sustainability. Because of the stoppages in the supply chain of various sectors economic crisis has occurred. The environment is severely affected as this causes harm to the natural environment. Social life is disturbed because the virus is very much infectious as it spread very rapidly in humans so, social distancing has been adopted as it’s the only solution to stay away from the virus and hence it results in work from home. By the term sustainability, it means our process or product should not harm the environment. The primary objective in any manufacturing organization is to obtain a certain level of productivity to have high performance without harming the environment. With modern technology and innovations to achieve this objective becomes easy relatively. Also, terms like ‘sustainability and ‘green’ environment have been emphasized because of degradation in natural resources and the high cost of human resources which makes the need for a high standard of living [1]. Initially, sustainability deals with the issues which are related to environmental impact such as usage of energy resources which has less or no negative impact on the environment [2]. According to Brundtland’s report, sustainability is defined as ‘the ability to meet the requirement of today's without damaging the requirement of future generations. The definition of environmental sustainability means to transform our standard of living so that the condition of the environment supports ecological balance, human security, and well-being. Sustainability has three dimensions i.e. economy, environment, and society which is also known as triple-bottom-line. In this paper, the graph theory approach is used for measuring the performance index and for inter-relation between each sustainability enabler. The main objective of this study is to measure the overall sustainability performance index pre and during COVID-19 using a graph-theoretic

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approach. The proposed approach is focused on various factors that are being affected by COVID-19. In Fig. 1 the dimensions of sustainability are shown i.e., economy, environment and social.

1.1. Economic sustainability

Economic sustainability involves the study of factors that are used to determine the production, distribution, and consumption of goods and services. The utmost goal of the economy is to improve the standard of living of people in their day-to-day life. Economy sustainability involves optimum utilization of available resources to secure for the future. Investing in the future becomes more significant as it underlines the motive of being sustainable. This is done by analyzing objectives, proper planning, adaptation of necessary measures, asset development. Taking an account of risk factors and managing them. Any organization will not attain success in the societal and environmental perspectives if it falls back in the economic sustainability perspective. Due to COVID-19 economy has been afflicted drastically as lockdown is shown in almost every part of the world [3]. Jobs have been lost continuously and ILO announced that worldwide 25 million jobs are lost [4]. In India, most people around 500 million involves in agricultural activities i.e. 15% of the GDP of India comes from the agricultural sector [5]. MSME and FDS sectors are affected because of lockdown in-country, unavailability of resources, and labour. The number of people living in India involved in manufacturing work is 111 million and production processes have been stopped to stop the spreading of COVID-19 [6]. The MSME is the foundation of a country’s economy [7] and adds to the GDP and creates job opportunities [8]. In this pandemic situation, we should involve in the process to build a resilient supply chain so that production and logistics can satisfy customer needs.

1.2. Environment sustainability

Environment sustainability involves the practices to save the mother nature and ecosystem to fulfill today’s needs without compromising future generations’ needs. An organization is said to achieve environmental sustainability if it takes decisions about processes and products that give less harm to the environment. Measures such as management of energy sources, wastage reduction strategies, lean manufacturing which means utilizing the existing resources efficiently, and adopting methods to reduce the maximum amount of wastes. Also, integration of technology into sustainability to secure the environment and resources by considering innovative methods. Because of lockdown, the quality of the air has been improved as social and economic activities have been shut down. The disposable face masks, PPE kit, hand gloves damage the environment. Also, huge waste that comes through hospitals creates negative environmental effects. Thus, it is suggested to dispose of the hazardous medical waste properly otherwise it increases the risk of disease transmission and exposure to the virus of waste workers. To reduce environmental pollution, it is necessary to save energy and conserve natural resources. The positive and negative environmental impacts of COVID-19 are shown in Fig. 2.

1.3. Social sustainability

Societal sustainability means the concern for the society when making manufacturing decisions so that it does not cause harm to the population, it seeks to contribute to human needs. Corporate social responsibility (CSR) enhances the societal sustainability objective it considers the decisions that favour human force but is not prosecuted by law. The outburst of COVID-19 has not only affected the economy and environment but has also attacked societies at a tremendous level.

2. Research methodology

This paper uses the graph-theoretic approach (GTA) to find out the performance index pre and during COVID-19 by considering attributes and sub-attributes. GTA is a mathematical and systematic approach that has a hierarchical structure, maintains inter-relationship and interdependencies among attributes [9]. Also, the advancement in graphs helps in the modelling and analysis of systems [10]. GTA is also used in the Indian mining industry to identify, classify, and rank the barriers to the green supply chain [11]. This approach is used to evaluate supply chain sustainability for small and medium-scale industries [12]. The basic elements in GTA are nodes and edges which are used to represent inter-relationship between nodes known as different variables or attributes in form of the directional graph also known as a digraph. Digraph is the representation of vertices connected with edges. As nodes depict selection attributes. The Selection attribute is defined as a factor that influences the best alternative selection decision. Conversion of digraph into a square matrix called relative importance of one attribute over other and the diagonal elements depict the individual importance of attributes to the system or inheritance. The digraph with respective matrix changes with change in the number of attributes, a standard form of matrix function which is known as permanent functions is evaluated rather than the determinant of the matrix. Researchers preferred to evaluate the permanent function of a matrix rather than the determinant function of a matrix because some information may be lost due to the presence of negative signs in case of the determinant of a matrix so to provide the complete information without any loss permanent function is eval-
In general, evaluation of the permanent function of an $M \times M$ matrix $A$ with attributes $a_{ij}$ is performed as follows:

$$\text{Per}(A) = \sum \Pi a_{ij} P(i)$$

$P(i)$ is the sum of overall permutations $P$. To calculate the permanent function value, a computer program for the $M \times M$ matrix was written in C++ language. This program takes a few minutes to run the program and computes the value of the permanent function. The GTA involves step by step methodology to find out the last result.

**Step: 1** Identify Attributes.

**Step: 2** Identify the sub-attributes of each selected attribute. SBSC is to be used to select attributes and sub-attributes. SBSC is a sustainable balanced scorecard used to measure system performance by selecting attributes and sub-attributes with triple bottom line aspects of sustainability.

**Step: 3** Make the digraph representing attributes and then convert the graph into the matrix.

**Step: 4** For the weights of interrelationship or relative importance among attributes take views from experts using sustainable balanced scorecard (SBSC) taking suitable scale shown in Table 2 and they represent off-diagonal elements of the matrix.

**Step: 5** Obtain diagonal elements or inheritance for the matrix as follows:

i. Each attribute is to be selected one by one and identify respective sub-attributes. Like, there are three attributes of sustainability in the proposed research, each attribute has six sub-attributes.

ii. Make a digraph for all the identified sub-attributes then convert the digraph into the matrix where off-diagonal elements represent the inter-relationship among sub-attributes.

### Table 1

Attributes and sub-attributes for the proposed study.

| Attributes | Sub-attributes |
|------------|----------------|
| 1. ECONOMIC(E) | i. Transportation(T) |
|  | ii. Unemployment (UE) |
|  | iii. Education(E) |
|  | iv. Labour(L) |
|  | v. Food Supply Chain (FSC) |
|  | vi. Agriculture(A) |
| 2. ENVIRONMENT(EN) | i. Increase in Medical Waste (MW) |
|  | ii. PPE disposal (PD) |
|  | iii. Less recycling waste (LRW) |
|  | iv. Human loss (HL) |
|  | v. Increase Municipal Waste (IMW) |
|  | vi. Air, water and soil pollution (AWS) |
| 3. SOCIAL(S) | i. Self-isolation (SI) |
|  | ii. Older person (OP) |
|  | iii. The person with a disability (PWD) |
|  | iv. Youth (Y) |
|  | v. Sports (S) |
|  | vi. Researchers (R) |

### Table 2

The relative importance of attributes.

| Description | $a_{ij}$ | $a_{ij} = 1 - a_{ij}$ |
|-------------|----------|-----------------------|
| Two attributes are equally important | 0.5 | 0.5 |
| One attribute ($i$) is slightly more important than the other ($j$) | 0.6 | 0.4 |
| One attribute ($i$) is strongly more important than the other ($j$) | 0.7 | 0.3 |
| One attribute ($i$) is very strongly important over the other ($j$) | 0.8 | 0.2 |
| One attribute is extremely important over the other | 0.9 | 0.1 |
| One attribute is exceptionally more important than the other | 1 | 0 |
iii. Take responses for weights of inheritance i.e., diagonal elements from a selected scale from the experts. In the proposed study, the scale present in Table 2 is used for the inter-relationship, and Table 3 is used for the inheritance.

iv. After taking the values of inheritance and interrelationship put the values in the matrix and compute the permanent function for the first attribute by using expression per(A). C++ Program can be used for computing the permanent function of the attributes.

v. Repeat the steps from 1 to 4 to compute the permanent function for all other two attributes.

**Step 6** Put the values of inheritance in the matrix and compute the permanent function of the selected scenario by using the expression per(A) or C++ program.

**Step 7** Compute the permanent function for each of the scenarios by repeating step 3 to step 6. This permanent function is referred to as the performance index.

**Step 8** Select the most impacted scenario based on the sustainability performance index of all the scenarios.

### 3. Case Illustration:

This section illustrates the step-by-step methodology as described to find out the performance index pre and during COVID-19. Experts were selected who are involved in the area of environmental management and sustainability. As COVID-19 distorts the sustainability factors, in this study the three attributes i.e., economy, environment, and social with each of them having six sub-attributes have been taken with the expert's opinion. The calculation is performed to find out the performance index before and during the COVID-19. In the proposed research there are two scenarios, the first case deals with the impacts on sustainability factors before COVID-19, and the second case deals with the impacts on sustainability factors during COVID-19. Based on the expert's opinion, the selection has been performed.

**Step 1:** Selection of attributes i.e., Sustainability has three attributes which are economy, environment and society as shown in Table 1.

**Step 2:** Selection of sub-attributes for each selected attribute as shown in Table 1.

**Step 3:** Plotting of digraph depicting selected attributes and convert digraph into the matrix as shown in Fig. 3.

**Step 4:** Take the expert's opinion to put the values to off-diagonal elements for scenario 1 and scenario 2 matrices by evaluating the permanent function of the sub-attributes matrices of each attribute by following sub-steps of step 5. Make a digraph for the sub-attributes representing six sub-attributes for each attribute, it contains six nodes corresponding to the six sub-attributes of each respective attribute as shown in Fig. 4. Also, inter-relationship among sub-attributes is shown by the directed edges. Then these digraphs are converted into respective matrices. The off-diagonal elements values are taken from Table 2 based on experts' opinions. The diagonal element values for respective scenarios are taken from Table 4. The values shown in Table 4 are based on the group of experts' opinions, selected from Table 3. The matrices are shown in the following steps along with computation of permanent function for all three perspectives with two scenarios. For two scenarios computation of permanent function of sub-attributes of three attributes has been shown in the following matrices (see Fig. 5).

(a) From the economic perspective, the following matrix is obtained as follows for scenario 1, here the values of the diagonal elements are taken from Table 4 i.e., 0.7, 0.5, 0.4, 0.6, 0.8, and 0.9. The value after evaluating the permanent function of the matrix i.e. 9.35404 is D_{11} for scenario 1 matrix.

**MATRIX FOR ECONOMIC PERSPECTIVE (FOR PRE-COVID)**

\[
A = \begin{bmatrix}
E & EN & S \\
E & D_{11} & 0.7 & 0.4 \\
EN & 0.3 & D_{12} & 0.8 \\
S & 0.6 & 0.2 & D_{13}
\end{bmatrix}
\]

**SCENARIO 2 (Performance Index Matrix for during covid):**

\[
B = \begin{bmatrix}
E & EN & S \\
E & D_{21} & 0.7 & 0.4 \\
EN & 0.3 & D_{22} & 0.8 \\
S & 0.6 & 0.2 & D_{23}
\end{bmatrix}
\]

**Step 5:** Compute the value of diagonal elements for scenario 1 and scenario 2 matrices by evaluating the permanent function of the sub-attributes matrices of each attribute by following sub-steps of step 5. Make a digraph for the sub-attributes representing six sub-attributes for each attribute, it contains six nodes corresponding to the six sub-attributes of each respective attribute as shown in Fig. 4. Also, inter-relationship among sub-attributes is shown by the directed edges. Then these digraphs are converted into respective matrices. The off-diagonal elements values are taken from Table 2 based on experts' opinions. The diagonal element values for respective scenarios are taken from Table 4. The values shown in Table 4 are based on the group of experts' opinions, selected from Table 3. The matrices are shown in the following steps along with computation of permanent function for all three perspectives with two scenarios. For two scenarios computation of permanent function of sub-attributes of three attributes has been shown in the following matrices (see Fig. 5).

(b) From the environment perspective, the following matrix is obtained as follows for scenario 1, here the values of the diagonal elements are taken from Table 4. This value would be D_{12} in the scenario 1 matrix.
For scenario 1, the values obtained by calculating the permanent function of sub-attributes are as follows $D_{11} = 9.35404$, $D_{12} = 10.0162$, $D_{13} = 7.00126$. 

Fig. 4. Diagraph for sub-attributes i.e for all three attributes (a) Economy. (b) Environment. (c) Social.

Matrix for Social Perspective (For Pre-COVID)

\[
\begin{bmatrix}
    - & MW & PD & LRW & HL & IMW & ANS \\
    MW & 0.3 & 0.4 & 0 & 0.3 & 0.4 \\
    PD & 0.7 & 0.6 & 0.3 & 0.4 & 0.2 \\
    LRW & 0.6 & 0.4 & 0.2 & 0.3 & 0.3 \\
    HL & 1 & 0.7 & 0.8 & 0.6 & 0.5 \\
    IMW & 0.7 & 0.6 & 0.7 & 0.4 & 0.5 \\
    ANS & 0.6 & 0.8 & 0.7 & 0.5 & 0.5 \\
\end{bmatrix}
\]

= 10.0162

(c) From the social perspective, the following matrix is obtained as follows for scenario 1, here the values of the diagonal elements are taken from Table 4. This value would be $D_{13}$ in the scenario 1 matrix.

Table 4

| Attributes | Sub-attributes                  | PRE COVID | DURING COVID |
|------------|---------------------------------|-----------|--------------|
| 1. ECONOMIC(E) | i. Transportation(T) | 0.7       | 0.4          |
|            | ii. Unemployment (UE)         | 0.5       | 0.9          |
|            | iii. Education(E)             | 0.4       | 0.9          |
|            | iv. Labour(L)                 | 0.6       | 0.8          |
|            | v. Food Supply Chain (FSC)    | 0.8       | 0.6          |
|            | vi. Agriculture(A)            | 0.9       | 0.5          |
| 2. ENVIRONMENT (EN) | i. Increase in Medical waste (MW) | 0.6       | 0.3          |
|            | ii. PPE disposal (PD)         | 0.5       | 1.0          |
|            | iii. Less recycling waste (LRW) | 0.4      | 0.6          |
|            | iv. Human loss (HL)           | 0.8       | 0.6          |
|            | v. Increase Municipal Waste (IMW) | 0.7      | 0.5          |
|            | vi. Air, water and soil pollution (AWS) | 0.9 | 0.6 |
| 3. SOCIAL(S)   | i. Self-isolation (SI)        | 0.2       | 0.8          |
|            | ii. Older person (OP)         | 0.4       | 0.5          |
|            | iii. Person with disability (PWD) | 0.5     | 0.6          |
|            | iv. Youth (Y)                | 0.7       | 0.9          |
|            | v. Sports (S)                 | 0.8       | 0.4          |
|            | vi. Researchers (R)           | 0.8       | 0.5          |

For scenario 1, the values obtained by calculating the permanent function of sub-attributes are as follows $D_{11} = 9.35404$, $D_{12} = 10.0162$, $D_{13} = 7.00126$. 

Fig. 5. Radar chart showing all three attributes.
For scenario 2, similarly same procedure is to be followed by taking diagonal elements values from Table 4. The matrix for scenario 2 has been shown as follows.

**MATRIX FOR ECONOMIC PERSPECTIVE (DURING COVID)**

\[
\begin{bmatrix}
T & UE & E & L & FSC & A \\
0.3 & 0.6 & 0.4 & 0.7 & 0.4 & \\
0.7 & 0.8 & 0.6 & 1 & 0.7 & \\
0.4 & 0.2 & 0.3 & 0.6 & 0.3 & \\
0.6 & 0.4 & 0.7 & 0.8 & 0.6 & \\
0.3 & 0 & 0.4 & 0.2 & 0.3 & \\
0.6 & 0.3 & 0.7 & 0.6 & 0.7 & \\
\end{bmatrix}
\]

\[D_{21} = 10.3878, D_{22} = 11.2526,\]

**MATRIX FOR ENVIRONMENT PERSPECTIVE (DURING COVID)**

\[
\begin{bmatrix}
MW & PD & LRW & HL & IMW & ANS \\
0.3 & 0.4 & 0 & 0.3 & 0.4 & \\
0.7 & 0.6 & 0.3 & 0.4 & 0.2 & \\
0.6 & 0.4 & 0.2 & 0.3 & 0.3 & \\
1 & 0.7 & 0.8 & 0.6 & 0.5 & \\
0.7 & 0.6 & 0.7 & 0.4 & 0.5 & \\
0.6 & 0.8 & 0.7 & 0.5 & 0.5 & \\
\end{bmatrix}
\]

\[= 11.2526\]

**MATRIX FOR SOCIAL PERSPECTIVE (DURING COVID)**

\[
\begin{bmatrix}
SI & OP & PWD & Y & S & R \\
0.4 & 0.3 & 0.7 & 0.5 & 0.7 & \\
0.6 & 0.4 & 0.8 & 0.7 & 0.8 & \\
0.7 & 0.6 & 0.8 & 0.7 & 1 & \\
0.3 & 0.2 & 0.2 & 0.4 & 0.6 & \\
0.5 & 0.3 & 0.3 & 0.6 & 0.7 & \\
0.3 & 0.2 & 0.4 & 0.3 & \\
\end{bmatrix}
\]

\[= 7.68257\]

For scenario 2, the values obtained from the permanent function of sub-attributes are \(D_{21} = 10.3878, D_{22} = 11.2526, D_{23} = 7.68257\).

### 4. Result

**Step 6 and 7**: Evaluation of performance index

Now put these diagonal elements values which are calculated by finding the permanent function of the sub-attributes matrix of each attribute matrix for both the scenarios into the attribute matrix of both scenarios, and compute the permanent function to get the values of the performance index for both the scenarios.

\[
A = \begin{bmatrix}
E & EN & S \\
9.35404 & 0.7 & 0.4 \\
0.3 & 10.0162 & 0.8 \\
0.6 & 0.2 & 7.00126 \\
\end{bmatrix}
\]

\[A = 661.692\]

\[
B = \begin{bmatrix}
E & EN & S \\
10.3878 & 0.7 & 0.4 \\
0.3 & 11.2526 & 0.8 \\
0.6 & 0.2 & 7.68257 \\
\end{bmatrix}
\]

\[B = 904.35\]

The value of the performance index for scenario 1 (pre-covid-19) is 661.692 and the value for scenario 2 (during covid-19) is 904.35.

**Step 8**: Selection of scenarios

Based on the performance index determined above, during COVID-19 the impact is more on sustainability enablers as compared to pre-COVID-19. We can conclude that during COVID-19 the impact on sustainability enablers i.e., economy, environment and social perspectives is more as compared with pre-COVID-19.

Hence, Scenario 2 > Scenario 1 in order of impact of COVID-19 on sustainability enablers.

### 5. Conclusion

Pandemic leads to disturbance of sustainable supply chain as it brings insubstantiality and improper functionality in every area. Therefore, it becomes important to study the impact of COVID-19 on sustainable supply chain enablers i.e., economic, environmental and social.

- This paper provides the analyses of economic, environmental and social parameters affecting sustainability.
- Section 1 introduces the impact of COVID-19 on Indian business and discusses the sustainability dimensions.
- Section 2 involves the research methodology that has been used in the proposed study i.e., the impact of COVID-19 (pre and during) on sustainability enablers with the help of GTA for the analysis, taking economic, environmental and social as attributes following their respective sub-attributes.
- Section 3 involves the case illustration that includes preferences and weightage to each attribute and the sub-attribute were provided with the help of experts and literature reviews.
- Section 4 gives the result of the proposed study in which the framework was developed using two scenarios that are pre-covid and during covid, attributes that are economic, environmental and social. The permanent function is carried out to find out the performance index which was evaluated with the help of the C++ program.
- Hence, if we consider the pre-covid scenario then the attribute environment was affecting the sustainable supply chain and in the during-covid scenario, the attribute that was affecting the sustainable supply chain is the environment only as calculated from GTA. This paper provides economic, environmental, and social impacts that occurred during lockdown because of deadly COVID-19.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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