14th Annual International Conference on Industrial Engineering and Operations Management
Dubai, United Arab Emirates (UAE), February 12-14, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240119
Published: February 12, 2024

Assessing Smart Green Supply Chain Management Practices in Manufacturing Companies of Saudi Arabia

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Abstract

The smart green supply chain (SGSC) is an emerging phenomenon because of the advancement of sustainable smart business and information technology trends. Various small and large enterprises are putting all their efforts into imbibing Industry 4.0 (I4.0) based disruptive technologies to transform their green supply chain management (GSCM) to be a smart green supply chain management (SGSCM) to fetch advantages of increased efficiency that leads to financial gain. Smart green supply chain management practices (SGSCMP) involving I4.0 disruptive technologies can provide greater transparency and quick decision-making. The SGSCMP must be assessed to work for I4.0 readiness to compete the global competitions. Hence, the present research attempts to assess the SGSCM-based practices adopted by manufacturers in KSA. Various SGSCMPs have been identified by carrying out the literature review. The Analytic hierarchy process with group decision-making (AHP-GDM) is used using the expert judgment of the expert group consisting of five experts. The expert group assessed the SGSCMP for their importance and three companies adopting such SGSCMP are analyzed for their ranking.

Keywords
Green supply chain management (GSCM), Smart green supply chain management practices (GSCMP), Analytic Hierarchy Process (AHP), and Group decision-making (GDM)

1. Introduction
The transformation of green supply chain management (GSCM) towards smart green supply chain management (SGSCM) will involve Industry 4.0 (I4.0) technologies that will provide the required “smartness:” to a company in their processes and technologies by enhancing data flow and its effective usage in cutting down and companies activities in real-time (Holmström *et al.*, 2019). GSCM entails incorporating sustainable environmental processes into traditional supply chains. It incorporates the 4R1D (reuse, reduce, reclaim, recycle, and degradable) philosophy throughout the manufacturing, operations, and end-of-life management processes. Smart green supply chain management lowers waste and is a sort of supply chain management system that optimizes the movement of goods and services from suppliers to customers by utilizing modern technology and automated data analysis methodologies.

A "smart green supply chain" is a concept that combines principles of sustainability and environmental responsibility with the use of advanced technologies and data-driven processes to create a more efficient, eco-friendly, and sustainable supply chain. It's an approach aimed at reducing the environmental footprint of supply chain operations while optimizing processes for cost-effectiveness and performance. These are the essential elements of a smart green supply chain. The smart SC helps the maker in a variety of ways. A smart system can anticipate a potential operational bottleneck caused by an event, and this type of event can be exploited to simplify the system and reduce waste from excess production. This can lead to leaner manufacturing and increased operational efficiency.

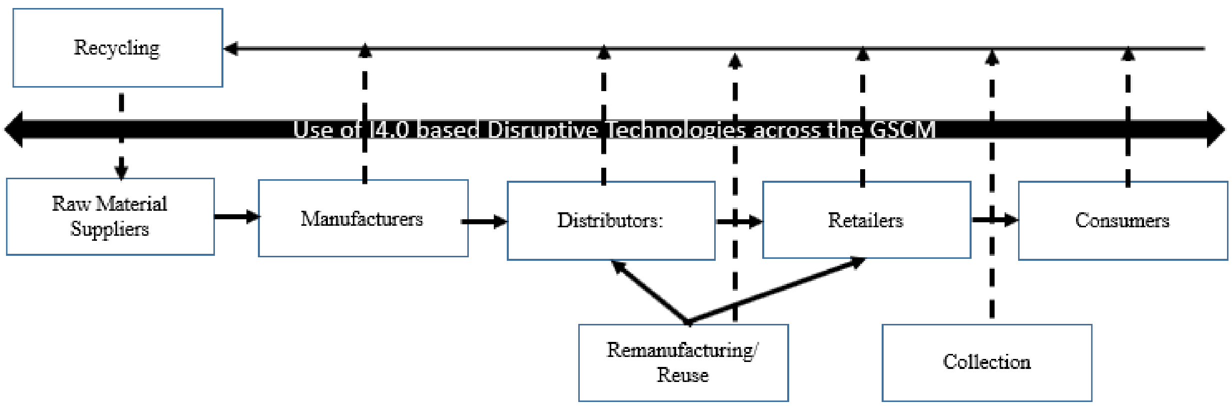

Figure 1. Use of I4.0-based disruptive technologies across the GSCM.

Figure 1 shows the SGSCM using I4.0-based disruptive technologies for efficient supply chain activities.

1.1 Objectives

The SGSCMP can lead to a better performance of a manufacturing supply chain that can further enhance the working environment, and cost saving and will lead to a better environmental management system. Hence, it is important to assess the SGSCMP of various manufacturers that intend to adopt GSC in their manufacturing practices. Thus, the present research has multifold objectives:

1. What are the various SGSCMPs for smart green SC performance?
2. How the firms be assessed based on their SGSCMP?

2. Literature Review

The green performance of a manufacturing supply chain may be enhanced by employing an I4.0-based technology across the supply chain. The green performance accomplished using a digital transformation was assessed using a configurational approach (Lerman *et al.*, 2022). Varipus's implication of process digitization on the practical implication of the supply chain has been studied (Holmström *et al.*, 2019). One of the studies investigated the joint effect of biofuel quality improvement and carbon emission-controlling activities in smart sustainable supply chain management having three echelons (Mridha *et al.*, 2023). A study attempted to help practising managers understand the IoT usage transforming sustainable supply towards smart SCM. The practising managers need to decide on the SGSCMP that is more relevant and enhances the smartness of SC (Shokouhyar, Pahlevani and Mir Mohammad Sadeghi, 2019). A study involving the use of green IoT put forward a framework depicting the data usage captured through IoT and its implication on environmental sustainability for GSCM (Nozari, Fallah and Szmelter-Jarosz, 2021). The adoption of disruptive technology plays a significant role in enhancing sustainable manufacturing supply chain for small and medium enterprises (SMEs)(Qureshi, Mewada, Kaur and Qureshi, 2023)(Qureshi, Mewada, Kaur, Alghamdi, *et al.*, 2023). Recently a study investigated the use of AI Chatbot for sustainable manufacturing supply chain performance of SMEs (Panigrahi *et al.*, 2023).

3. Method

The AHP is a decision-support model that follows a systematic and scientific process (Saaty, 1987). It offers a variety of applications in several decision areas (Qureshi, Kumar and Kumar, 2007). The expert knowledge, skills and understanding may be deployed in pairwise comparisons for better decision-making. Using expert group feedback, a meaningful decision may be obtained. It is widely known that a single expert may be biased in his/her decision-making and may result into an incorrect result. However, group decision-making (GDM) can make use of more experts forming a group thus it may avoid bias in decision-making. Several experts may be involved who may form a decision which may be considered as a unbiased decision-making (Table 1).

Table 2. Saaty's Pairwise comparison scale

The intensity of Relative Importance	Definition
1	Equally preferred
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate importance between two adjacent judgments

AHP process may be listed into various steps as shown below:
Step 1:
All SGSCM-based practices may be transformed into a single matrix known as decision comparison matrix 'A'. Every practice of SGSCM forms an element for matrix 'A'. The Saaty's 9-point scale may be used for pairwise comparison. Each element of the matrix 'A', a_{pq}, is normally compared by experts considering its importance for its p^{th} comparison with that of the q^{th}.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1k} \\ a_{21} & d_{12} & \dots & da_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ a_{k1} & a_{k2} & \dots & a_{kk} \end{bmatrix} \quad (1)$$

Step 2:
In case of more than one decision matrix, the geometric means (GM) based synthesising process can be adopted. Experts from the expert group carry out the pairwise comparison of the matrices. The final weight of the matrix is obtained using the GM process.
Step 3:
A principal eigenvalue denoted by (λ_{max}), is calculated by using Equation (2).

$$\lambda_{max} = \sum_{i,j=1}^{k} C_j PV_i \quad (2)$$

where c_j shows the column sum vector.
Step 4:
The consistency index (CI) may be obtained from the decision matrix using Equation (3):

$$\text{CI} = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

The matrix size gives the value of n.
Step 5:
The random index (RI.) is significant in getting the Consistency Ratio (C.R.). The Equation (4) may be used for RI values.

$$\text{RI} = \frac{1.98\ (n-2)}{n} \quad (4)$$

Step 6:
The Consistency ratio (CR) for each pairwise decision matrix may be calculated by dividing CI by. Generally, CR of less than 10% is considered to be consistent.

4. Case Study

Various manufacturers practising SGSCM-related practices and eager to use I4.0-based disruptive technologies were identified and consulted. Based on their interest in the present study, three manufacturing companies were identified. The identified companies were Tissue Manufacturing Company. Glass Manufacturing Company and Aluminum Chanel Manufacturing Company. Further, eight SGSCM-based practices like Waste reduction & recycling practices (P1), Green Transportation Usage (P2), Sustainable sourcing practices (P3), Carbon footprint measurement (P4), Green procurement practices (P5), Disruptive technologies usage (P6), Environmental compliance practices (P7) and

Eco-labelling of products (P8) were identified. The identified three companies were practising the various SGSCMP. The background of the three companies under study is given below:

Tissue manufacturing company: The companies manufacture various types of tissue by using a fabrication process that generates more waste. The company is interested in its SGSCM-based practices. The company is running in its seventh year and taking care of 20% of the market requirement in the Aseer region. The company is attempting to reduce their waste by imbibing automation and recycling.

Glass manufacturing company
The company manufactures various types of commercial and industrial glass used by the construction industries and private firms. The company is interested in its SGSCM practices. The company is running in its third year of establishment. The company is attempting to increase its market share in the Aseer region.

Aluminum Chanel manufacturing company
The company under study manufactures various types of Aluminum Chanel using a fabrication process. The waste generation during the process is more which the company is interested in reducing by employing SGSCM practices.

5. Results and Discussion

In all, eight DGSCMPs were identified and included in the assessment. AHP-GDM methodology was adopted based on the pairwise decision of an expert group consisting of five experts. The five experts were engineering graduates having working experience of 5 years. The expert group also has good exposure to DGSCM practices. The expert group were also given hands-on practice with the AHP-GDM pairwise comparison procedure and its calculation. Table 2 provides a comparison of eight DGSCMPs carried out by expert 1. Table 3 provides the combined results of all five experts from the expert group. Table 4 provides the assessment of various companies under study. Figure 1 SGSCM practice assessment of companies under study.

Table 2. Pairwise comparison by Expert 1 of SGSCMP

No.	SGSCMP	P1	P2	P3	P4	P5	P6	P7	P8	Weights
1	Waste reduction & recycling practices (P1)	1	2	1	2	1/3	1/2	1/5	1	0.0799
2	Green Transportation Usage (P2)	1/2	1	2	3	1/4	1/6	1/5	1/3	0.0650
3	Sustainable sourcing practices (P3)	1	1/2	1	3	1/3	1/2	1/2	1/4	0.0763
4	Carbon footprint measurement (P4)	1/2	1/3	1/3	1	1/3	1/3	1/2	1/2	0.0506
5	Green procurement practices (P5)	3	4	3	3	1	1/3	1	3	0.1852
6	Disruptive technologies usage (P6)	2	6	2	3	3	1	1	2	0.2244
7	Environmental compliance practices (P7)	5	5	2	2	1	1	1	2	0.2009
8	Eco-labelling of products (P8)	1	3	4	2	1/3	1/2	1/2	1	0.1178

CI=0.1320, RI=1.4100, λ_{max}=8.9243, CR=0.0937

Table 3. Combined results of pairwise comparison by all experts of SGSCMP

Sr.No.	SGSCMP	P1	P2	P3	P4	P5	P6	P7	P8	Weights
1	Waste reduction & recycling practices (P1)	1.00	1.26	2.47	3.42	0.33	0.27	0.29	0.55	0.0829
2	Green Transportation Usage (P2)	0.79	1.00	1.10	2.08	0.31	0.17	0.24	0.33	0.0547
3	Sustainable sourcing practices (P3)	0.41	0.91	1.00	1.82	0.24	0.22	0.24	0.25	0.0473
4	Carbon footprint measurement (P4)	0.29	0.48	0.55	1.00	0.35	0.29	0.22	0.27	0.0404
5	Green procurement practices (P5)	3.00	3.17	4.22	2.88	1.00	0.33	0.63	0.79	0.1463
6	Disruptive technologies usage (P6)	3.68	6.00	4.61	3.48	3.00	1.00	1.00	1.26	0.2474
7	Environmental compliance practices (P7)	3.42	4.22	4.16	4.61	1.59	1.00	1.00	1.26	0.2157
8	Eco-labelling of products (P8)	1.82	3.00	4.00	3.68	1.26	0.79	0.79	1.00	0.1654

CI=0.0410, RI=1.4100, λ_{max}=8.2867, CR=0.0290

Table 4. Combined result of pairwise comparison by all experts of SGSCMP for companies under study

Sr. No.	SGSCMP	Local Weight	Local weight			Global weight		
			Tissue Co.	Al Chanel Co.	Tissue Co.	Tissue Co.	Al Chanel Co.	Tissue Co.
1	Waste reduction & recycling practices (P1)	0.0829	0.058	0.066	0.066	0.005	0.006	0.005
2	Green Transportation Usage (P2)	0.0547	0.058	0.050	0.053	0.003	0.003	0.003
3	Sustainable sourcing practices (P3)	0.0473	0.050	0.046	0.045	0.002	0.002	0.002
4	Carbon footprint measurement (P4)	0.0404	0.032	0.033	0.033	0.001	0.001	0.001
5	Green procurement practices (P5)	0.1463	0.147	0.153	0.152	0.022	0.022	0.022
6	Disruptive technologies usage (P6)	0.2474	0.336	0.257	0.270	0.083	0.063	0.067
7	Environmental compliance practices (P7)	0.2157	0.219	0.223	0.212	0.047	0.048	0.046
8	Eco-labelling of products (P8)	0.1654	0.100	0.173	0.170	0.016	0.029	0.028
					Normal weights in %	34.04	32.94	33.02
					Companies rank practicing SGSCM	1	3	2

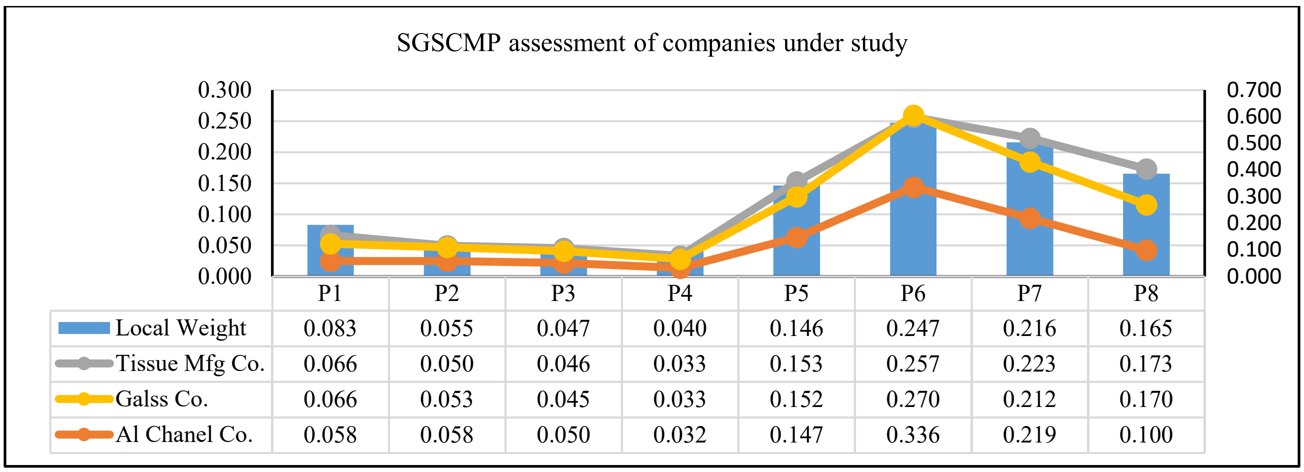

Figure 1. SGSCM practice assessment of companies under study

6. Conclusion

The present research attempts to assess the SGSCM-based practices using the AHP-GDM approach for various companies namely Tissue Manufacturing Co., Glass Manufacturing Co. and Al Chanel Manufacturing Co. It is revealed from the results that SGSCMP is largely adopted by all the companies under study. The identified eight SGSCM-based practices have been normally practised by the companies and found that they are eager to adopt more I4.0-based technologies. It is found that various SGSCMPs like Disruptive technologies usage (P6), Environmental compliance practices (P7) and Eco-labelling of products (P8) play significant roles in GSCM. The results revealed that the Tissue Manufacturing Co. is leading in SGSCM-based practices followed by Glass Manufacturing Co. and Aluminium Chanel Manufacturing Co.

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Biography

Ali Saeed Almuflih is an assistant professor and chair of the industrial engineering department at the College of Engineering, King Khalid University. His research interest lies in the intersection of operations management and data analytics, in particular, as applied AI to healthcare delivery system framework, supply chain engineering, lean concepts, Smart and Green Supply chain management, Project management, etc. He has completed his PhD in Industrial Engineering in the Department at the University of Central Florida (UCF) in 2020, USA. He also previously received a M.Sc. degree in the Department of Mechanical & Industrial Engineering at Northeastern University (NEU) in 2015 and a B.Sc. in the Department of Industrial Engineering from King Khalid University (KKU) in 2011. He published several research papers in high-ranking journals.