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ORIGINAL ARTICLE

Risk assessment in sustainable supply chain: theoretical and managerial implications for circular economy in emerging economies

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Abstract In recent times, sustainable supply chain (SSC) management has received significant attention from academics and industries. Due to its complex nature, various risk sources are involved in SSCs. Thus, evaluation of risks in SSC becomes critical in enhancing the resilience and efficiency. Accordingly, this paper develops a framework for evaluating the most influential risks in an SSC using multi-criteria decision-making method. Using a data triangulation strategy, the study finalized 20 risks from the list of 25 risks. The finalized risks are evaluated and prioritized using multi-objective optimization ratio analysis technique. The findings show that the environmental supply chain is critical for SSC as it plays a key role in enhancing SSC performance. Based on the outcomes, the study suggests that the industries should prefer closed-loop supply chain practices rather than traditional linear supply chain practices. Also, the industries must incorporate 6R (Rethink, Refuse, Reduce, Reuse, Recycle, Repair) practices in the regular industrial activities. Furthermore, the findings help academics and industrial managers to achieve sustainability and circularity in supply chains.

Keywords Sustainable supply chain · MOORA · Data triangulation strategy · MCDM · Circular economy

1 Introduction

Supply chain management plays a crucial role in the success of a business. With increasing new needs, strict environmental regulations, and the requirement to ensure timely delivery of products to the market, supply chain management must comply with environmental norms (Luthra et al. 2018). In addition to the environmental norms, the concept of sustainable supply chain management (SSCM) is gaining attention among industries and academics. The SSCM concept is well received by mature markets as well as emerging markets (Rebs et al. 2018). To adopt the sustainability concept within supply chain management, industries must consider social, economic, and environmental aspects to achieve complete success. SSCM can be defined as the transparent integration, strategy, and accomplishment of environmental, economic, and social goals (Koberg and Longoni 2019). Given the development and implementation of sustainability theories across nations, there is a need to clearly understand sustainability practices in supply chain management. The evolution of audits, strict regulations, and sustainability certifications develop the supply chain to meet global standards. Because of these standards and challenges, many scholars and practitioners have been fully attracted to supply chain management practices. However, an increase in competition among businesses, the impact of globalization, the increased awareness of sustainable development goals (SDGs), and unlimited expectations from the customers generate a heightened number of uncertainties and risks for SSCM (Karuppiah et al. 2020).

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Because SSCM is a critical objective, it exposes industries to higher-level risks due to global economic uncertainties, developments in information technology (IT), and in-creased offshoring/outsourcing activities. Hence, risk management has been recognized as a critical activity in the supply chain domain. As a supply chain involves various phases, the number of risks associated is higher and needs special attention (Bathrinath et al. 2021b, a). Unexpected and uncertainty involved with the incidence of any event is termed as a risk factor. Although a concrete definition of supply chain risks is not available, (Gouda and Saranga 2018) define supply chain risks as the potential deviations from the objectives that could decrease the value-added activities at different levels. The risks may evolve from economic, social, and environmental aspects and may significantly influence the SSC (Bhalaji et al. 2019). Financial shortage may stall supply chain activities for an undefined period when economic risks are considered. Likewise, when a labor strike occurs, the activities associated with the supply chain are affected to a large extent. Non-adherence to the environmental norms may affect the industry's reputation in society. It is essential for industrial managers to recognize the most influential risk factors, particularly when the resources in risk management are limited (Ritola et al. 2020). Technically, the risks involved in the supply chain may be inbound risks, process risks, or shipment risks. In this concern, an industry must have a reliable and resilient supply chain network to handle all evolving risks. In the progress towards attaining SSC, many countries and industries seek to adopt circular economy practices. With a circular economy, it is possible to reduce wastes and to recover value from that waste (Karuppiah et al. 2021).

Bappy et al. (2019) used Dempster-Shafer theory, along with analytic network process (ANP) method, to evaluate various risks involved in SSC management. Azadi et al. (2015) created a Russell measure model for choosing the best sustainable supplier in a resin production firm and they assessed the effectiveness and efficiency of suppliers in SSC using fuzzy development analysis. The created model will be helpful for decision makers to manage environmental, social, and economic risk factors when choosing sustainable suppliers. In a telecommunication industry, risk factors in SSC have been recognized using a rough, weighted decision making trial and evaluation laboratory (DEMATEL) method. Failure to choose right suppliers is the most prominent challenge, and it is a major concern for enhancing SSC as can be observed from the results (Song et al. 2017). In a textile industry, a failure mode and effect analysis (FMEA) is used for risk assessment; this method is applied to evaluate the relative significance of risks and to recognize potential risks and their relationships. Based on relevant findings, environmental supply chain management is the most critical one; its severity is very high in this industry (Giannakis and Papadopoulos 2016). Rostamzadeh et al. (2018) developed a model for SSC and evaluated the risks using a MCDM method that combines fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) and criteria importance through inter-criteria correlation (CRITIC) approaches. Fluctuation in demand, supplier failures, and poor sewage infiltration are the most influential challenges in the oil industry. Best worst method (BWM) is applied to evaluate the criteria for environmental sustainability in a study based in Bangladesh. The findings depicted that waste management is the key indicator and it is very helpful to practitioners for achieving environmental sustainability (Suhi et al. 2019).

From the above information, it is clear that there is a growing awareness of SSCM among multiple industries. The risks associated with the SSCM are also getting increased attention due primarily to the complexity of the supply chain network. Overall, the incorporation of sustainability in supply chain management has been a compelling subject area for industries. Because of the integral role of sustainability, industries must pursue a framework for addressing the risks involved in SSCM. Considering these identified needs, this study intends to propose a reliable framework that can assist industries to manage the risks associated with SSCM. This study develops some central research questions, as given below, and tries to answer them suitably.

1. What are the major risks involved in SSC?
2. Which risk is the most prominent one to SSC?
3. What are the interrelationships among the various risks?
4. Which control measures should managers take to help them achieve a SSC?

Industries desire to be more efficient in the production process to accomplish SSCM in their business. However, they may face various hurdles while implementing the SSCM practices. As per the industry needs, the motivation of the paper is to find the most influential risk factors in SSCM using MCDM method. The outcome of the paper will be surely helpful for industrial managers and practitioners for the effective SSCM in an industry.

This paper conducts a contextual case in a medical equipment manufacturing industry in south India to address the above research questions. In this study, a multi-objective optimization model based on the ratio analysis (MOORA), an MCDM (multi-criteria decision making) technique, is used to evaluate the risks involved in sustainable supply chain management. Here, the MOORA technique is preferred over other MCDM techniques as it provides a comprehensive result by making a direct comparison among the risks. In addition, many earlier studies have utilized MOORA in different applications such as health risk assessment (Dabbagh and Yousefi 2019), public transport quality

(Moslem and Çelikbilek 2020) and logistics provider selection (Mavi et al. 2017).

This study contributes significantly to the literature on SSCM. Firstly, this study provides a comprehensive list of risks associated with SSCM. Secondly, this study prioritizes the listed risks based on their significance level. Such prioritization will give the sequence for which industries should address these risks. Thirdly, this study reveals the relationships among the risks. Understanding these relationships provides better insights into the risks. Finally, this study also proposes some control measures that may assist industries in overcoming the risks.

A conventional supply chain is merely confined to the timely delivery of the products to the correct place with the correct quantity (Abdel-Basset et al. 2018). Under this traditional constraint, the only responsibility for the supply chain department is to predict the demand earlier and alert the production system. In some situations, the supply chain department may face difficulties in correctly predicting the demand and, as a result, an imbalance between supply and demand may occur (Wang et al. 2018). However, in recent times, the paradigm of the supply chain network has undergone a drastic transition. Some paradigm shifts in a supply chain include IoT-based supply chains and blockchain-enabled supply chains (Aryal et al. 2018). As a result, in addition to the existing challenges like natural disasters or network collapse, the technological challenges associated with supply chain management are also getting complicated. In recent times, the concept of sustainability is gaining importance in the supply chain network circle (Koberg and Longoni 2019). While the literal meaning of sustainability is to meet the current requirements by utilizing the resources without over-utilizing the resources belonging to the future, the sustainability concept is applied in all industrial spheres. As a result, the concept of the sustainable supply chain is also devised. When viewed from the sustainability perspective, risks may evolve not only from technical and operational aspects but also from social, economic, and environmental aspects. Recent trends like outsourcing, globalization, and customization complicate the functioning of the supply chain networks. Such complications threaten the ability of the logistics providers, manufacturers, and end-beneficiaries to deliver and avail the services (Ghavamifar et al. 2018). A study by (Elluru et al. 2019) indicates that supply chain disruption accounts for 50,000 to 500 million Euros. Besides incurring a financial loss, supply chain disruption also brings in a loss of reputation, reduced productivity, and customer loss. To ensure profitability and timely product delivery, the supply chain management must be aware of the risks associated with supply chain activities and risk mitigation strategies.

After identifying various risks that the industry may encounter, industries need to identify suitable risk assessment methods to mitigate risks. As the first step in risk assessment, the likelihood of the risks and their impact must be evaluated. Supply chain risk assessment is an organized approach for finding, evaluating, prioritizing, and monitoring potential disruptions in the supply chain to mitigate the negative impact of these disruptions in the supply chain activities (Rajagopal et al. 2017). For an effective risk assessment, the nature of the risks, various parameters influencing the risks, and their impact must be measured (Li et al. 2015). Only by understanding the nature and the impact of the risks clearly can industries select appropriate risk mitigation strategies. Risk mitigation strategies are generally categorized under preventive and reactive risk mitigation strategies (Qazi et al. 2017). Although both risk mitigation strategies are devised to reduce the impact of risks, preventive measures safeguard the industries before a risk event occurs, while reactive measures aim to address the risks after an occurrence. The choice of risk mitigation strategies may be preventive or reactive based on the technical capability of the industries. Industries must have distinguished risk mitigation strategies for routine supply chain disruption from any catastrophic disruption occurring unexpectedly (Fagundes et al. 2021). However, many industries lack awareness of the need to have resilient risk mitigation strategies that need to be used in averting the risks associated with supply chain activities. Developed economies invest more in developing and enhancing supply chain performance by adopting a circular economy strategy. The major advantage of adopting a circular economy is that the industries can mitigate the adverse environmental impacts and recover value from the wastes (Karuppiah et al. 2021). However, the adoption of the circular economy by the emerging economies is very scant. A poor response from the emerging economies is because of a lack of awareness of the circular economy. A review of (Shekarian et al. 2022) indicates that SSCM are those which allow industry to raise their profit by considering the three layers of sustainability such as economic, environmental and social aspects. For the effective organizational performance, SSCM provides valuable insights into the strategic tools identification, resource utilization and operational structure (Fu et al. 2022).

Based on the information from the above-reviewed literature, it is evident that risks associated with the supply chain activities have a potentially adverse impact on business progress. Hence, it becomes essential to have sufficient knowledge of the various risks expected to occur in the supply chain activities that may influence productivity. Further, after reviewing the existing literature, it is evident that many industries are unaware of the risk mitigation strategies. Hence, it is essential to shed light on the importance and benefits of risk assessment and mitigation strategies. Accordingly, this study aims to propose a framework for identifying and prioritizing the risks associated with supply chain activities. To demonstrate the effectiveness of the proposed framework, this study applies the framework in an Indian industry. The reason for selecting India as a case reference is that India is an emerging economy and is recognized as a manufacturing hub. Also, India is one of the important countries in the global supply chain network. The objectives of this study are as follows:

1. To identify the major risks involved in SSC.
2. To prioritize the identified risks in SSC based on their severity.
3. To reveal the interrelationships among every identified risk.
4. To suggest some needed control measures that may be taken by managers for achieving SSC.

The details and steps involved in the MOORA technique used for the evaluation of the risks are discussed: Multi-objective optimization ratio analysis (MOORA) is used to recognize the most influential SSC risks for achieving and implementing the performance of a sustainable supply chain (Fagundes et al. 2021). Brauers initiated the MOORA method in 2006, which is deliberated as a non-subjective (objective) method (Brauers and Zavadskas 2006). Furthermore, both undesirable and desirable criteria are used at the same time for ranking to choose higher or superior alternatives among various alternatives. Recently, many researchers used this method for different applications and solving problems (Deniz Basar and Guneren Genc 2019; Sahoo et al. 2019; Yusuf Tansel İç 2020).

1.1 Research gap and contributions

The research gap identified in the paper revolves around the insufficient awareness and understanding of risk mitigation strategies within various industries, particularly in the context of supply chain activities. Despite recognizing the potentially adverse impact of supply chain-related risks on business progress, there appears to be a knowledge gap regarding the specific risks and effective mitigation measures. This lack of awareness underscores the need for research that not only highlights the importance and benefits of risk assessment and mitigation strategies but also addresses the existing gap by proposing a comprehensive framework for identifying and prioritizing supply chain risks and also emphasizing the necessity of further research to bridge the knowledge divide and contribute to the enhancement of risk management practices in industries, especially in the Indian context.

The contribution of this study lies in its mathematical and theoretical advancements within the context of risk assessment in sustainable supply chain using MOORA method. Mathematically, the study introduces a novel application of the MOORA (Multi-Objective Optimization by Ratio Analysis) method to assess and prioritize risks in the sustainable supply chain. The method allows for a quantitative evaluation of risk factors, considering their interrelationships and influences on supply chain performance. Theoretically, the study contributes by extending the understanding of risk assessment in sustainable supply chain management (SSCM). It introduces a comprehensive framework that not only identifies and distinguishes risk factors but also addresses the complex interconnections between them. This contributes to the theoretical foundations of SSCM by offering a practical and effective methodology for risk evaluation. Furthermore, the study enhances existing theoretical frameworks by incorporating the MOORA method, which excels in handling subjective and vague data. This contributes to bridging the gap in risk assessment methodologies, particularly in situations where traditional models may be limited.

Table 1 shows to identify the gap and fundamental difference between the current and existing studies.

Table 1 Difference between current and existing studies

Reference(s)	Factor	Subfactor
Abdel-Basset and Mohamad, 2020 and Zimon et al. 2020	Environmental	Greenhouse gas emission, Hazardous waste generation
	Social	Human rights, Quality of life of communities
	Economic	Price Volatility, Order fulfilment rate, Tax evasion, economic recession
	Operational	HR risks, Loss of key equipment
Current study	Environmental	Generation of hazardous waste, Natural disasters, Inefficient use of resources & Environmental Pollution
	Social	Poor working environment, Business ethics violation, Discrimination & Child labor
	Economic	Reduction in market share, Loss of reputation, Tax evasion & Expenditures in development & research
	Operational	Risks in information sharing and IT, Poor skill in sustainable, Uncertainty in supply and demand, Lack of quality at supply source & Failure to choose correct suppliers

2 Methodology

2.1 Data collection

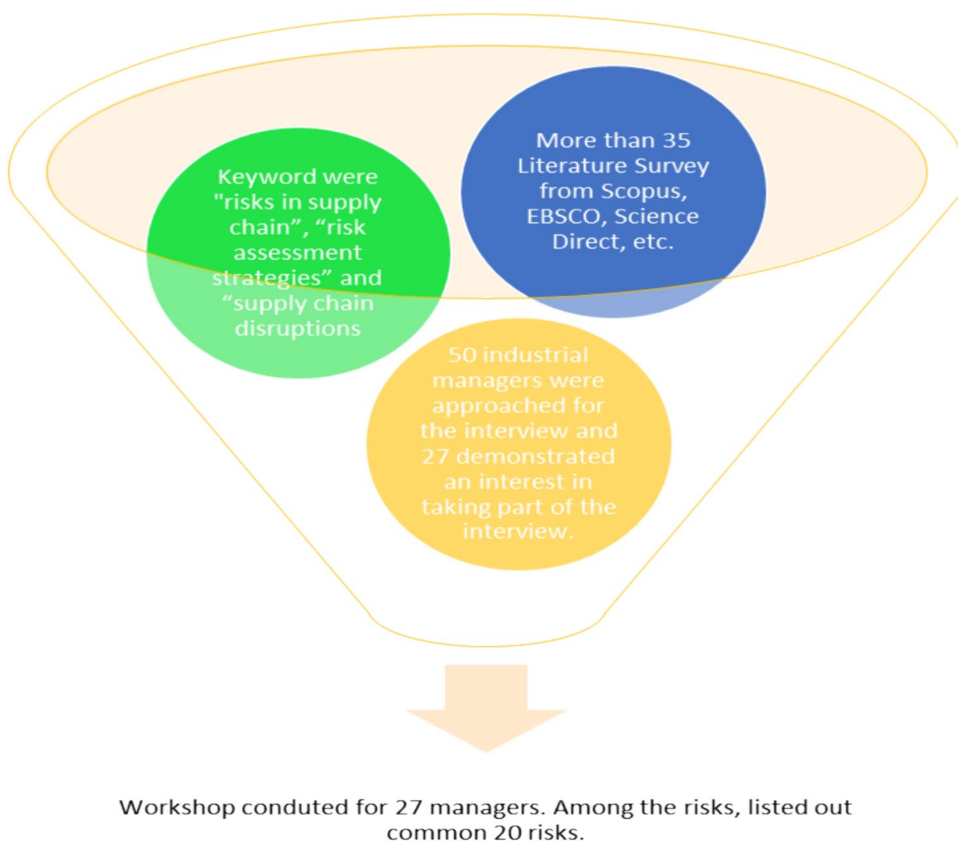
The first phase of this study focuses on data collection. For this purpose, a data triangulation strategy is employed. In this strategy, data are gathered from three distinct sources:

1. Firstly, a literature survey was conducted using scientific databases such as SCOPUS, EBSCO, Web of Science, and Science Direct. Keywords like "risks in the supply chain," "risk assessment strategies," and "supply chain disruptions" were utilized to search for relevant research articles. Initially, 65 research articles were retrieved from these databases. However, 27 articles were excluded due to reasons such as non-English manuscripts, duplication, or replication. The final selection comprised 65 articles published between 2016 and 2021, from which 25 risk factors were identified.
2. Secondly, 50 industrial managers were initially approached for interviews, out of which 27 expressed interests in participating. In-depth interviews were conducted with these 27 industrial managers between April and May 2021. The interviews began with an explanation of sustainable supply chain management concepts, followed by discussions on the associated risks. Industrial managers were asked to share the risks they encountered in their respective supply chain activities.
3. Finally, a workshop was organized for the 27 managers. They were presented with a list of the 25 identified risks and asked to mark those they encountered. Collating their responses, the 20 most commonly encountered risks were selected and summarized. These finalized risks are presented in Table 2. They were then shared with an expert panel, who categorized them into four main factors along with sub-factors, as depicted in Table 2. The methodology of data collection is illustrated in Fig. 1.

Table 2 Linguistic terms and their relevant scores

Relevant scores	Linguistics terms
4	Very high influence
3	High influence
2	Low influence
1	Very low influence
0	No influence

Fig. 1 Methodology of data collection



2.2 MOORA technique

The methodological framework used in this study is illustrated in Fig. 2. The framework adopted in this study consists of two phases. In first phase, the various risks involved in SSC practices are identified using literature review and inputs from experts. In the second phase, the risks identified in first phase are analysed, prioritized, and the interrelationships among the risks are revealed. For this purpose, the MOORA technique is used. For identifying the critical risks associated with the supply chain, a team of ten experts is formed. The risks collected via literature review are discussed with the experts to confirm their appropriateness and frequency. The strategy followed for confirmation of the risks is discussed in Sect. 1.

This method has several helpful features: (a) independent attributes; (b) qualitative attributes are easily changed into quantitative attributes; and (c) the approach corresponds to compensatory methods. Table 2 depicts the linguistic terms and their relevant scores. Table 3 represents risk factors involved in SSC.

Step 1: Eq. (1) is used to find the input data of this method with the help of decision matrix.

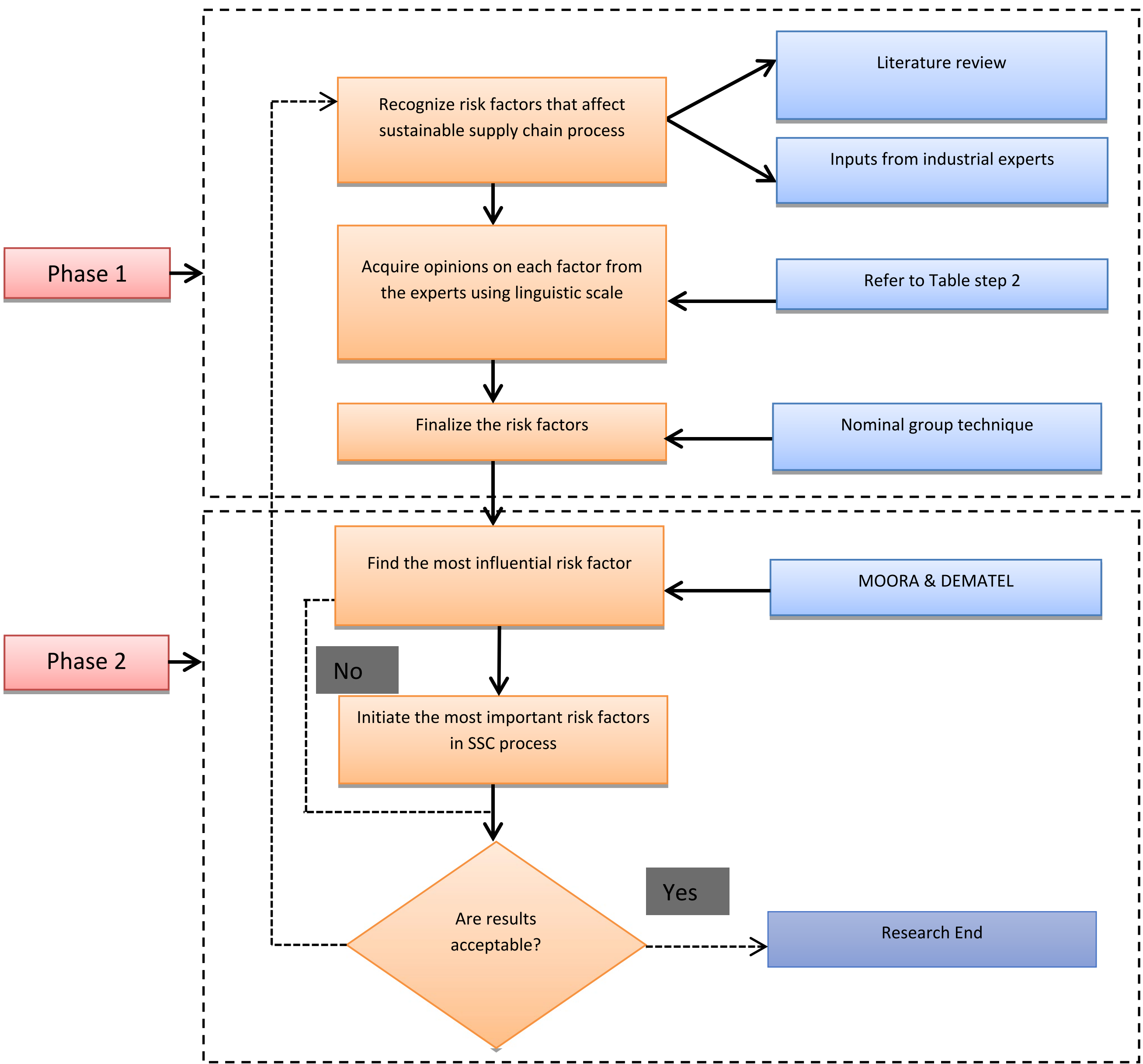


Fig. 2 Suggested framework of this paper

Table 3 Risk factors involved in SSC

Factors	Sub-factors	References
Environmental (S1)	Generation of hazardous waste (S11)	(Ritola et al. 2020; Wang et al. 2018)
	Natural disasters (S12)	(Bappy et al. 2019; Luthra et al. 2018)
	Environmental pollution (S13)	(Rajagopal et al. 2017)
	Emission (S14)	(Fagundes et al. 2021)
	Inefficient use of resources (S15)	(Luthra et al. 2018)
Social (S2)	Human rights violation (S21)	(Rajagopal et al. 2017)
	Poor working environment (S22)	(Aryal et al. 2018; Bappy et al. 2019)
	Business ethics violation (S23)	(Song et al. 2017)
	Discrimination (S24)	(Fagundes et al. 2021; Ritola et al. 2020)
	Child/forced labor (S25)	(Koberg and Longoni 2019)
Economic (S3)	Reduction in market share (S31)	(Bappy et al. 2019)
	Loss of reputation (S32)	(Giannakis and Papadopoulos 2016)
	Price volatility (S33)	(Koberg and Longoni 2019)
	Tax evasion (S34)	(Giannakis and Papadopoulos 2016; Luthra et al. 2018)
	Expenditures in development & research (S35)	(Gouda and Saranga 2018; Luthra et al. 2018)
Operational (S4)	Risks in information sharing and IT (S41)	(Fagundes et al. 2021; Ritola et al. 2020)
	Uncertainty in supply and demand (S42)	(Aryal et al. 2018)
	Poor skill in sustainable (S43)	(Rajagopal et al. 2017; Song et al. 2017)
	Lack of quality at supply source (S44)	(Mavi et al. 2017)
	Failure to choose correct suppliers (S45)	(Giannakis and Papadopoulos 2016; Gouda and Saranga 2018)

$$Y = \begin{bmatrix} s_{11} & \cdots & \cdots & s_{1m} \\ s_{21} & \ddots & \cdot^{\cdot^{\cdot}} & s_{2m} \\ s_{31} & \cdot^{\cdot^{\cdot}} & \ddots & s_{3m} \\ s_{n1} & \cdots & \cdots & s_{nm} \end{bmatrix}_{n\times m} \quad i = 1, ..., n, \cdot j = 1, ..., m \tag{1}$$

In Eq. (1), s_{ij} signifies the decision matrix element for alternative i^{th} in attribute j^{th}. The experts give the attribute weight $\left[v_1, v_2, ..., v_n\right]$ relevant to normalized property $\left(\sum_{j=1}^{m} v_j = 1\right)$.

Step 2: Eq. (2) is used to determine the NDM (Normalized Decision Matrix).

$$s_{ij}^{*} = \frac{s_{ij}}{\sqrt{\sum_{i=1}^{n} s_{ij}^{2}}} \; j = 1, ..., m \tag{2}$$

In that equation, s_{ij}^{*} shows the decision matrix normalized value of alternative i^{th} in attribute j^{th}.

Step 3: Points of reference.

Deliberating the negative or positive state of every attribute, the points of references for the attributes positive are highest values and attributes negative are lowest values.

Step 4: Values of assessment.

Regarding the attribute weight $\left[v_1, v_2, ..., v_n\right]$ the values of assessment of every attribute is determined through Eq. (3).

$$\hat{z}_j = \sum_{j=1}^{k} s_{ij}^{*} \cdot v_j - \sum_{j=k+1}^{m} s_{ij}^{*} \cdot v_j; i = 1, ..., n \tag{3}$$

In that equation, where $[m - k]$ denotes the negative attributes number and k shows the positive attributes number, and as per the attribute type, the ideal points of the attribute j^{th} are reduced from all attribute values of the j^{th}.

Step 5: Alternatives final ranking.

As per the preceding step, the attained maximum values of $\left(\hat{z}_i\right)$ are found for alternative i^{th}, then the values are prioritized in a descending order, and the maximum amount has the top rank.

After finalization, the risk factors are evaluated based on the inputs of the experts.

3 Data analysis

The application of MOORA technique in evaluating the identified risks is demonstrated with a real time case study at a medical equipment manufacturing industry. Industry XYZ is a leading multinational corporation that sells and manufactures medical equipment products such as hearing aids, ECG machines, X-ray equipment throughout the world. Because of the stakeholders' requirements, increasing competition, stricter regulations and resources exacerbating scarcity, Industry XYX has planned to spend resources in SSC.

Increased offshoring/outsourcing activities and ambiguity of global economy in market bring several risks to SSCM for the XYZ industry. Ten experts with skill in suppliers' interaction from various functions in XYZ industry are invited to participate; they are chosen based on their experience and their decision-making skills. This group of experts gives a broad supply chain (both suppliers and customers) attention with work experience. The following section explains the steps involved in MOORA technique along with real time application:

Step 1: Using Table 1, the experts were asked to pair-wise comparison between the factors and sub-factors. The pair-wise comparison made by the experts is shown in Table 4. Table 4 shows the average of the ten experts' response.

Step 2: The pair-wise comparison matrix obtained from the experts are normalized using Eq. (2). The normalized decision-matrix obtained using Eq. (2) is given in Table 5.

Step 3: From Table 6, the reference points are selected.

Step 4: Now, Eq. (3) is used to calculate the assessment values. The calculated assessment values are shown in Table 7.

Step 5: Finally, the rank of the factors are calculated and are shown in Table 8.

3.1 DEMATEL

DEMATEL is a kind of MCDM method. This method is used to identify the most influential risk factor or enabler and also it is used in variety of applications such as environmental health and safety, green manufacturing, sustainable supply chain, waste management etc. The procedure for DEMATEL is referred using following literatures (Bathrinath et al. 2022; Bhalaji et al., 2021). Figure 3 shows the flowchart for the DEMATEL method.

As per Tables 8 and 9, both MOORA and DEMATEL revealed the same results. Finally, the results are benchmarked by comparing with the results obtained using DEMATEL method.

4 Results

The outcomes of the risk factor recognition provide major implications to the practice and theory, thus contributing to the management of risk in the SSC field. Managers in supply chain departments can take mitigation measures to evaluate and control the recognized risk factors. From the perspective of theory, this research creates a framework and SSC risk recognition method at the same time considering the influence and positive/negative attributes of risk factors. Industrial managers have lack of knowledge about the interactions of risk factors in SSC (Caiado et al. 2021). The suggested framework may be utilized to comprehend the risk factors interactions. With the assistance of MCDM method, SSC can turn 'pro-active', because it can support risk management direction by finding how SSC risk factors impact each other. The suggested MOORA framework shows the interrelationships between risk factors and it assists industrial managers to take financially and environmentally reasonable decisions. Based on the results obtained from Table 7 (i.e., alternative values), environmental risk is the most influential one in SSC. Environmental factors (S1) secure the top position among the risk factors to a circular economy. It was followed by the operational factors (S4), economic (S3), and social (S2) factors. Further, the interrelationships between the risk factors are shown in a radar diagram in Fig. 4.

5 Discussions

This study has obtained the following outcomes.

1. Recognition of risks related to the sustainable supply chain in the South Indian medical equipment manufacturing industry.
2. In this study, MOORA was used to recognize the most influential risk.
3. For the decision matrix, MOORA was used by gathering data from academic experts, literature, and industrial managers in the Indian context.
4. As per alternative values, environmental risk attained the highest one, and it is the most influential risk.

Environmental supply chain management is a major concern to be played by functional activities involvement such as reuse, reduction, recycling, materials substitution, and purchasing (Karuppiah et al. 2021). By adopting circular economy practice, it is possible to create a working

Table 4 Decision matrix

	S11	S12	S13	S14	S15	S21	S22	S23	S24	S25	S31	S32	S33	S34	S35	S41	S42	S43	S44	S45
S1	3	3	4	3	2	2	1	2	3	2	3	3	3	2	2	2	2	1	2	1
S2	4	3	3	4	3	3	1	2	3	1	2	3	3	2	2	2	2	2	2	1
S3	3	2	3	4	3	2	2	1	1	3	3	3	2	3	2	2	2	3	2	2
S4	3	2	3	3	4	2	1	2	3	2	3	3	3	3	2	2	3	2	2	1

Table 5 Normalized decision matrix

	S11	S12	S13	S14	S15	S21	S22	S23	S24	S25	S31	S32	S33	S34	S35	S41	S42	S43	S44	S45
S1	0.070	0.115	0.093	0.060	0.053	0.095	0.143	0.154	0.107	0.111	0.097	0.083	0.097	0.077	0.125	0.125	0.125	0.043	0.125	0.100
S2	0.093	0.115	0.070	0.080	0.079	0.143	0.143	0.154	0.107	0.056	0.065	0.083	0.097	0.077	0.125	0.125	0.125	0.087	0.125	0.100
S3	0.070	0.077	0.070	0.080	0.079	0.095	0.286	0.077	0.036	0.167	0.097	0.083	0.065	0.115	0.125	0.125	0.125	0.130	0.125	0.200
S4	0.070	0.077	0.070	0.060	0.105	0.095	0.143	0.154	0.107	0.111	0.097	0.083	0.097	0.115	0.125	0.125	0.125	0.130	0.125	0.200

Table 6 Reference points

Sub-factors	S11	S12	S13	S14	S15	S21	S22	S23	S24	S25	S31	S32	S33	S34	S35	S41	S42	S43	S44	S45
Value	0.093	0.115	0.093	0.06	0.053	0.095	0.286	0.077	0.036	0.167	0.065	0.083	0.097	0.077	0.125	0.125	0.125	0.13	0.125	0.1

Table 7 Assessment values

	S11	S12	S13	S14	S15	S21	S22	S23	S24	S25	S31	S32	S33	S34	S35	S41	S42	S43	S44	S45
S1	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0050	0.0038	0.0056	0.0028	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0043	0.0000	0.0000
S2	0.0000	0.0000	0.0012	0.0010	0.0013	0.0024	0.0030	0.0038	0.0036	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0022	0.0000	0.0000
S3	0.0012	0.0019	0.0012	0.0010	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0016	0.0000	0.0016	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0040
S4	0.0012	0.0019	0.0012	0.0000	0.0026	0.0000	0.0030	0.0050	0.0036	0.0028	0.0016	0.0000	0.0000	0.0019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0040

Table 8 Final ranking of factors using MOORA

	Value	Rank
S1	0.0056	1
S2	0.0038	4
S3	0.004	3
S4	0.005	2

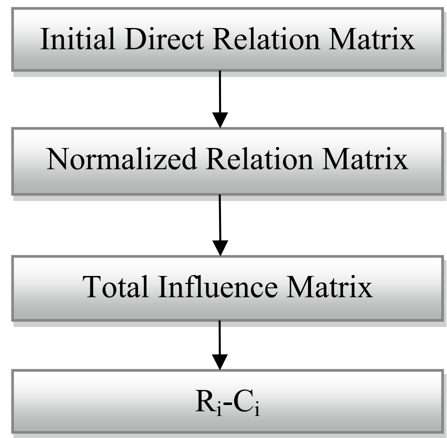


Fig. 3 DEMATEL Flow Chart

Table 9 Final ranking of factors using DEMATEL

	R_i-C_i	Rank
S1	9.67	1
S2	8.36	4
S3	9.22	3
S4	8.81	2

environment where the quantity of waste generated is minimized. For environmental issues, working with suppliers not only creates environmental benefits but also introduces chances for an improved product image, risk management, and containment cost. These accomplishments will assist industries in creating cooperative and long-term supplier relationships. Industries carefully defend environmental changes when faced with issues in customer satisfaction or in cost reduction. Generation of hazardous waste is the critical challenge in the environmental supply chain. Managers should evaluate monitoring the generation of hazardous waste through the evaluation of environmental performance with suppliers. The industry should reduce using hazardous substances in manufacturing or products and encourage collaboration with suppliers for lean production.

Operations in supply chain management illustrate the second ranked challenge in the SSC of a medical equipment manufacturing industry. It covers the whole organization: how business receives, creates, plans, and fulfils products (Tönnissen and Teuteberg 2020). Major activities

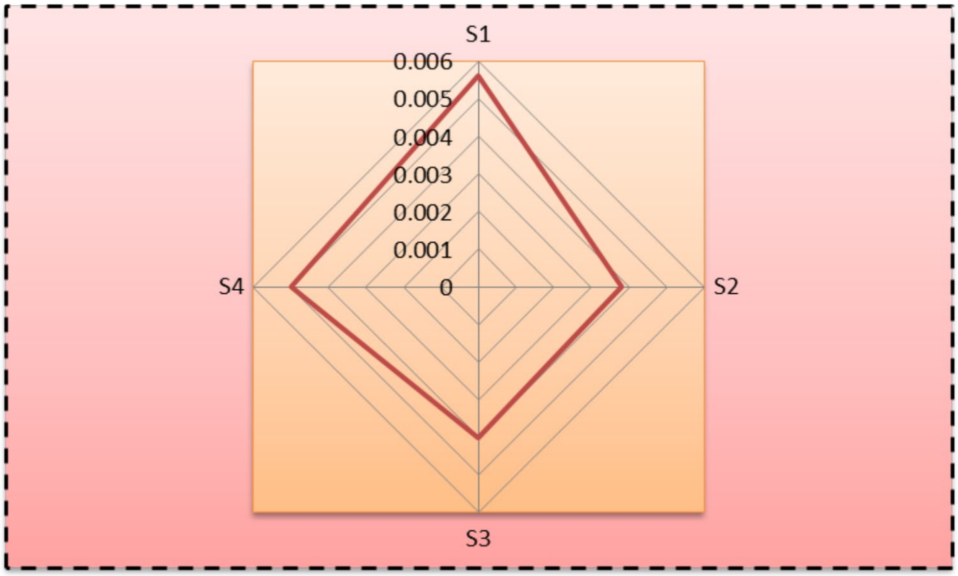


Fig. 4 Radar diagram for interrelationships between risk factors

are involved in the process such as maintaining, improving, and monitoring a broad spectrum of both collaborative and internal process. To develop relationships with customers and suppliers, demand management, customer service, manufacturing flow, fulfilment of order, and enhanced product and commercialization are essential components for effective operations in supply chain management. Failure to choose the correct suppliers is the key task in supply chain operation; in other words, choosing the correct suppliers with higher performance of sustainability on environmental, economic, and social goals is a fundamental goal (Pradhan et al. 2020). This choice influences the social and environmental concerns of SSC, because the selection of a supplier is a major role in accomplishing the three pillars of sustainability. Industrial managers must force supplier evaluation requirements for controlling risks in SSC. Further, to earn reputation from the society, the various stakeholders involved in the supply chain network need to adhere to the circular economy principle. This study is one of few initial attempts for both small and large-scale industries in India and all other emerging economies regarding maintenance and adoption of circular economy practices by considering the risks recognized here.

Generation of hazardous wastes (S11) can be eliminated by adopting circular economy practices. By restricting the generation of hazardous wastes, it is possible to check environmental pollution (S13) by keeping the products in use as much as possible. To achieve this, the operation department must be efficient and reliant in making the wastes generated into a useful product as long as possible. For such a need, the operation department should be enhanced with the most updated technological assistance. To be successful in a circular economy, adequate quantity and quality of the wastes must be supplied. For this, the risk factors of Lack of quality at the supply source (S44) and Failure to choose correct suppliers (S45) must be addressed. Only a correct supplier could reliably supply the required quality of materials. Hence, more importance must be given to supplier selection. Further, adopting circular economy practice will help the industries recover loss of reputation (S32). By adopting a circular economy, the industries can earn a green image brand. Also, it helps the industries to position themselves as an environmentally friendly functioning industry (Karuppiah et al. 2021; Sarkar et al. 2021). From the government side, tax exemption must be given to the products developed through a circular economy. Also, the government must promote the circular economy concept among the industries by announcing certain subsidies for industries who successfully adopt a circular economy. In addition, awareness must be created among the public regarding products developed through the circular economy, and that the quality of such products is no longer inferior to virgin products.

5.1 Validation of outcomes

The final stage of this study is to verify the outcomes. After that outcomes were send to the industrial experts; after that, they consulted with other experts, verified with existing literature, and finally accepted the outcomes and frameworks. After their verification and acceptance, finalized outcomes and frameworks are presented to the medical equipment manufacturing industry. If industry implements the outcomes, indeed improvements like productivity, organizational performance, turnover, reliability and environmental protection will be increased and will benefit the stakeholders to a great extent. Additionally framework applied in this study could be used to various industries such as chemicals, textiles, plastics, and pharmaceuticals to analyse risks related to sustainable supply chain.

The findings of this study revealed both similarities and differences to the existing literature. In terms of environmental factors, our findings align with the study by (Bappy et al. 2019) regarding the generation of hazardous waste and environmental pollution. Furthermore, building upon this comparison, we have identified additional factors such as natural disasters and inefficient use of resources based on the study by (Centobelli et al., 2021) which highlights the broader environmental impact of sustainable supply chains. Additionally, it emphasizes the significance of greenhouse gas emissions as a critical sub-factor in sustainable supply chain management.

Regarding social factors, our study corroborates the concerns raised by previous research, including issues related to poor working environments, business ethics violations, discrimination, and child labor. To provide a more comprehensive understanding, we have incorporated insights from the studies by (Caiado et al. 2021) and (Elluru et al. 2019), which further explore social aspects such as community engagement and social responsibility within sustainable supply chain management. Moreover, this highlights the importance of social impact assessment and stakeholder engagement as essential sub-factors in sustainable supply chain practices.

In the economic dimension, our study shares similarities with the existing literature in terms of risks such as reduction in market share, loss of reputation, and tax evasion. To enrich this comparison, we have included findings from the study by (Ghavamifar et al. 2018) which delve into economic factors such as financial performance and supply chain cost optimization. Additionally, it emphasizes the significance of economic sustainability and long-term financial viability as crucial sub-factors in sustainable supply chain management.

In the operational dimension, our study aligns with the research conducted by (Gouda et al. 2018) regarding risks related to information sharing, lack of quality at the supply source, and failure to choose correct suppliers. To further enrich this comparison, we have incorporated operational risks such as supply chain disruption and process inefficiencies. Furthermore, it emphasizes the importance of agility and adaptability as essential sub-factors in sustainable supply chain practices.

5.2 The role of third-party reverse logistics providers in closed-loop supply chains

In the context of sustainable supply chains, closed-loop practices aim to minimize waste and maximize the recovery and reuse of materials throughout the product life cycle. While many companies strive to establish closed-loop supply chains, not all have the necessary recycling or remanufacturing capabilities in-house. This is where third-party reverse logistics providers play a crucial role in enabling the implementation of closed-loop practices. Third-party reverse logistics providers specialize in managing the collection, transportation, and processing of used or end-of-life products and materials. They act as intermediaries between companies and recycling or remanufacturing facilities, ensuring the smooth flow of products and materials within the closed-loop supply chain. By leveraging their expertise and resources, third-party providers offer valuable services that allow companies to participate in closed-loop practices, even if they do not have their own recycling or remanufacturing facilities.

Collaboration and partnerships between companies and third-party reverse logistics providers are essential for the effective management of closed-loop supply chains. When selecting a third-party provider, companies should consider factors such as their experience in handling specific product types, their network of recycling or remanufacturing facilities, and their ability to meet sustainability goals. Clear communication channels and information sharing mechanisms should be established to ensure seamless coordination between all parties involved. By working closely with third-party providers, companies can optimize the collection, sorting, and processing of used products or materials, ensuring their proper recycling, refurbishment, or remanufacturing. This collaboration contributes to the overall sustainability and circularity of the supply chain by minimizing waste generation, conserving resources, and reducing environmental impact.

5.3 Technical and institutional sustainability in the developed model

Technical sustainability refers to the application of technologies and practices that support sustainable outcomes. In the context of our research, technical sustainability encompasses the adoption of eco-friendly manufacturing processes, the use of renewable energy sources, the implementation of waste reduction strategies, and the integration of clean technologies. These technical aspects play a crucial role in achieving sustainable supply chain practices by minimizing environmental impacts and resource consumption. Institutional sustainability, on the other hand, focuses on the organizational and institutional frameworks that support sustainable practices. This includes policies, regulations, standards, and governance structures that promote sustainability throughout the supply chain. In our research, institutional sustainability is vital for ensuring compliance with environmental regulations, fostering collaboration among supply chain stakeholders, and establishing sustainability-oriented procurement practices. It also involves building partnerships with suppliers, customers, and other stakeholders to drive collective sustainability efforts.

Both technical and institutional sustainability are interconnected and mutually reinforce each other. By integrating technical sustainability measures and aligning them with institutional frameworks, companies can create a supportive environment for sustainable supply chain practices. This involves establishing sustainability targets, monitoring performance, and implementing continuous improvement initiatives. Moreover, companies need to engage in stakeholder dialogue and collaboration to address sustainability challenges collectively and drive industry-wide change.

6 Implications of the study

6.1 Theoretical implications

This study offers some significant contributions to the existing research that examines the risks involved in SSC management. First, this study provides a comprehensive list of risks involved in SSC management based on literature review and expert inputs. Such combined assistance captures the risks identified in earlier studies and is cross-examined with the experts to confirm the risks. Second, this study evaluates the risks using the MOORA technique. With the MOORA technique, the identified risks are evaluated based on the reference value. Next, the proposed framework will help the industrial practitioners and policy makers in developing a robust and resilient supply chain network. Finally, this study allows researchers to understand the impact of each risk and to rank those risks in SSC management. The provided list of risks will enhance the researchers in identifying suitable solution for a developing nation like India and for other developing nations.

To adopt and maintain circular economy practices in the medical equipment manufacturing industry, it must recognize risks related to a sustainable supply chain. In this study, four major risks are recognized which have been prioritized based on alternative values. The interrelationships between four risks will be helpful for industrial managers to focus on suitable risks at the time of implementing circular economy practices. Industrial managers may use this research to understand how circular economy practices may supply a better advantage for them, whereas not implementing these practices may affect their industrial performance. Circular economy practices within industries and academia are demonstrated to enhance sustainable supply chain processes. Finally outcomes suggest that commitment from top management will be needed for the effective implementation of circular economy practices in the medical equipment manufacturing industry. Also, this circular economy strategy helps reduce material consumption by minimizing the generation of waste, reusing waste materials, and providing guidelines to industrial managers in developing circular economy strategies to accomplish a sustainable supply chain. Finally, the recognized risk will help industrial managers implement the industry's circular economy practices proactively.

6.2 Managerial implications

The following managerial implications are suggested from the obtained outcomes.

1. Check and monitor hazardous waste generation using the evaluation of environmental performance.
2. The industry should maintain strong policies and legislation for circular economy practices to accomplish sustainable development.
3. Industry should avoid hazardous substances in production or manufacturing products.
4. Improve the customer and supplier relationship, order fulfilment, and manufacturing flow for the most effective supply chain operations.
5. Enhance the existing "5S" (Sort, Set in Order, Shine, Standardize, Sustain) in the workplace and also incorporate "6R" (Rethink, Refuse, Reduce, Reuse, Recycle, Repair) practices in industrial activities for achieving sustainability in supply chain activity. How each R can guide managerial decision-making and actions to promote sustainability and resource efficiency is discussed below.
6. Rethink: Managers should focus on reevaluating and challenging business models and existing processes to recognize more sustainable alternatives. This can be achieved by exploring technologies, eco-friendly materials and alternatives as well as by conducting life cycle assessments to recognize environmental impacts.
7. Refuse: Companies should actively refuse or minimize the use of materials and resources that are not environmentally friendly or not essential for their operations. This can be achieved through careful selection of suppliers and materials that align with sustainability goals.
8. Reduce: Managers has the authority to take decisions and emphasize the reduction of resource consumption throughout the supply chain and it involves assessing products, operations and processes to recognize opportunities for reducing resource inputs. This can be accomplished by implementing lean manufacturing principles & energy efficient technology and practices, optimizing production processes to diminish generation of waste and adopting technologies that promote efficiency. Regarding sustainable impact, it will directly contribute to cost savings, resource conservation and lower environmental impact.

9. Reuse: Management need to encourage the reuse of products and materials inside the organization or throughout the supply chain process. This can be achieved by establishing systems for redistributing and refurbishing used items, closed-loop systems and designing products for reusability. Regarding sustainability impact, reuse increases the lifespan of products and materials, minimizing the new resources need and generation of waste.
10. Recycle: Companies should prioritize the materials recycling at the end of this life cycle. Implement effective recycling programs and practices to ensure the proper disposal and recovery of materials. Companies should collaborate with recycling facilities, explore circular economy initiatives, and educate employees and stakeholders about the importance of recycling. Regarding sustainability impact, it will decrease the environmental impact related with raw materials extraction, resources conservation and reduction in landfill waste.
11. Repair: Management should focus on reparability and maintenance aspects in decision-making and product design. Encourage product repair and maintenance to prolong their lifespan and reduce the need for replacement. This can involve offering repair services, providing spare parts, and designing products with modularity and ease of repair in mind.

7 Conclusion

To identify the most influential risk factor in the context of sustainable supply chain (SSC), this paper employs the MOORA method. The proposed framework not only identifies and distinguishes interrelationships among SSC risk factors but also provides concise information for risk-based decision-making, offering flexibility in ranking outcomes. Notably, it excels in handling subjective and vague data, addressing the ambiguity inherent in individual judgments. Unlike other multi-criteria decision making (MCDM) methods, the MOORA method simplifies implementation for industrial managers by not requiring extensive data, such as distribution data or fuzzy membership functions. This method facilitates a comprehensive understanding of risk interactions, aiding in the development of practical implications and control measures for practitioners. It serves as a valuable tool for supply chain managers, drawing attention to emerging risk issues that could impact SSC performance. Furthermore, the framework is versatile and can be applied to various contexts beyond the scope of this study.

The study's findings offer valuable insights for industrial managers seeking to eliminate or reduce risks while implementing sustainable supply chain management (SSCM). Specifically, in the medical equipment manufacturing industry, if the proposed frameworks are implemented, improvements in supply chain effectiveness, environmental performance, productivity, safety, profit, and reliability are anticipated, benefiting stakeholders significantly (cho et al. 2012).

The study's key contributions include:

1. Identifying a comprehensive list of SSCM risks in the medical equipment manufacturing industry through literature review and insights from industrial experts.
2. Developing and proposing a MOORA-based framework to rank risks and capture their interrelationships based on expert opinions.
3. Visualizing the structure of interrelationships and offering suggested measures for the risk mitigation process.
4. Providing managerial implications related to issues such as hazardous waste generation, customer and supplier relationships, enhancing 5S, incorporating 6R practices, and avoiding hazardous substances linked to risks in the medical equipment manufacturing industry.
5. Guiding industrial managers in making tactical and strategic decisions for the effective implementation of 6R practices in the South Indian medical equipment manufacturing industry.

This paper acknowledges certain limitations that should be considered. Primarily, the assessment of risk factor ratings relies on expert judgments, introducing a degree of subjectivity that could complicate the decision-making process. To address this limitation, future research could refine risk ratings by incorporating considerations of the occurrence probability of the risk factors and their specific impacts on SSC performance. This approach would enhance the objectivity and reliability of the risk assessment process.

Additionally, the current study is limited to a single case industry, which may affect the generalizability of the findings. To overcome this limitation, future applications of the framework in diverse industries would be beneficial. Expanding the scope to multiple case industries would provide a more comprehensive understanding of the framework's effectiveness and robustness across different contexts, thereby enhancing its applicability and relevance.

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Declarations

Conflict of interest The authors declare of having no conflict of interest.

Ethical approval All studies were conducted in accordance with principles for human experimentation as defined in the declaration of Helsinki and its later amendments or comparable ethical standards.

Informed consent Informed consent after explaining the nature of investigation was obtained from each participant in this study.

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