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ABSTRACT

Finding new, creative ways to improve the performance of their supply chains is one of the biggest problems that manufacturing organizations confront in the age of globalization and competition. To achieve better performance, companies should engage in networking activities such as integrating with other supply chain participants. Manufacturing businesses also face sustainability issues caused by suppliers' practices that fail to meet sustainability criteria. In this sense, developing a collaborative relationship with a supplier is essential for successfully implementing sustainable practices and gaining a competitive edge. Therefore, it is imperative for manufacturing companies to effectively manage their relationships with their suppliers by strengthening their suppliers' commitment to sustainability. The concept of sustainable supplier collaboration (SSC) emerges from the combination of sustainability and supplier relationship building. SSC, in general, broadens the traditional supplier management system by incorporating long-term partnerships into the sustainable aspects. Companies have begun to acknowledge the value of SSC and are taking initiatives in this regard. The adoption has been extremely slow, despite the assurances of sustainable collaboration with suppliers. Hence, research is required to determine how supplier collaboration with economic, environmental, and social promises has been hindered. It is important to acknowledge any hurdles that manufacturing organizations may have while developing SSC. Also, a thorough analysis of these barriers is essential so effective and sustainable collaboration with suppliers can be achieved. Therefore, the primary goal of the study is to identify and analyze barriers to sustainable collaboration with suppliers. The integrated methodology of Total Interpretive Structural Modelling-Decision Making Trial and Evaluation Laboratory (TISM-DEMATEL) is used to achieve the purpose of study. An extreme case scenario involving one manufacturer of home appliances and its suppliers is used in a dyadic India based case study. The findings of this study reveal that the most significant barriers to SSC are lack of manufacturer-supplier communications for sustainable standards and appropriate regulations, lack of trust between manufacturer and supplier, lack of scope and focus for sustainable collaboration, unwillingness to share risks and rewards, lack of top management involvement, lack of combined training programs, and lack of consistent and adequate performance measurement systems. These barriers not only contribute directly to hindering SSC efforts but also influence other barriers at intermediate and lower levels. Additionally, the study offers detailed explanations of each barrier, thereby providing valuable insights for better understanding and effective implementation of sustainable manufacturer-supplier collaboration (SMSC).

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1. Introduction

In large developing economies, companies are increasingly forming collaborative relationships with their supply chain partners so they can strategically compete in the marketplace (Duong and Chong, 2020). Collaborative relationships push companies to move away from individualism and to indulge in networking such as integration with other supply chain participants (Jimenez-Jimenez et al., 2018). One of the core collaborative relationships in a supply chain is the manufacturer-supplier relationship as it facilitates sustainable practices, competitive advantage, and improved supply chain performance (Govindan et al., 2021). Companies recognize the importance of their roles and, accordingly, they proactively seek to adopt sustainable manufacturer-supplier collaborations designed to improve business performance, market share, revenue, and customer satisfaction (Liu et al., 2021). Furthermore, suppliers, as key members of supply chain, account for 50–80% of total product cost. With the largest percentage of investment, a strong supplier relationship is vital for a company's success. Hence, companies are actively turning to greater sustainable supplier collaboration.

As per the report of Zurich insiders during 2019, 51.9% of companies faced supply chain disruptions during the COVID-19 pandemic and more that 75% of companies were affected (Zurich, 2022). Hence, to achieve a competitive edge in the market, it is crucial for companies to collaborate with suppliers and to combine their strengths. But companies are witnessing challenges in the management of supplier relationships due to unaligned plans with suppliers and lack of trust.

The concepts of sustainability have attracted many researchers recently (Kannan et al., 2021, 2023). The integration of sustainability with supplier relationship building generates the concept of sustainable manufacturer supplier collaboration (SMSC). Generally, SMSC extends the traditional supplier management system by including long term relationships under sustainable aspects (Gutierrez et al., 2020). Many studies have confirmed that SMSC is a crucial factor for cost reduction, stability, managing risks, improved communication, building trust, sharing best practices, and enhanced sustainable performance (Wlazlak et al., 2019). It has been observed that open communication, long term relationships, regular meetings, and supply chain visibility have a positive impact on SMSC (Baah et al., 2021). Despite recognizing the importance of SMSC and taking appropriate steps in this direction, the adoption of SMSC is still an insurmountable problem. SMSC is understood as a 'key of business's success', but its adoption is very slow. Thus, it is obvious that certain barriers in the minds of the manufacturer and supplier must discourage them from sustainable collaboration. A lot of studies have examined the topic of manufacturer-supplier collaboration (Feng et al., 2020; Govindan et al., 2021). Many of these studies stalled at the pilot stage; consequently, no study has pursued challenges that underscore the adoption of SMSC. Hence, an investigation needs to be done into how economic, environmental, and social issues have obstructed manufacturer-supplier collaborations. The possible barriers that manufacturers and suppliers might face while developing a SMSC need to be recognized. The current study provides a relatively new approach by considering sustainability dimensions for barrier investigation. This approach focuses on identifying barriers that prevent the implementation of SMSC in a supply chain and tries to figure out the reason behind manufacturers and suppliers not adopting SMSC, especially when both exhibit willingness towards the same. For identifying and listing the barriers, the literature survey, experts' opinions, and our own scholarly knowledge have been utilized. Hence, an extensive list of 19 barriers of SMSC is compiled and presented. Furthermore, a questionnaire is prepared for collecting information regarding the constructs of SMSC implementation. After that, the integrated methodology of Total Interpretive Structural Modelling-Decision making trial and evaluation laboratory (TISM-DEMATEL) is utilized. The basic idea of this methodology is to decompose the complex problems into several sub elements and to build a multilevel structural model (Tan et al., 2019). TISM-DEMATEL methodology presents several distinct advantages when compared to existing comparison methods such as Interpretive Structural Modelling (ISM), Decision making trial and evaluation laboratory (DEMATEL), Heterogeneous Influence and Strength Attenuation (HISA) etc. TISM-DEMATEL surpasses ISM by quantifying relationships, determining influence directions, and accommodating feedback loops. Unlike ISM, TISM-DEMATEL assigns numerical values to interdependencies, thereby enabling a more precise understanding of barrier relationships. Moreover, it unveils cause-and-effect dynamics and handles cyclic dependencies, providing a comprehensive and actionable analysis for complex problems. DEMATEL focuses only on cause-and-effect dynamics, while TISM-DEMATEL allows for the examination of both hierarchical relationships (how SMSC barriers are structured) and causal relationships (how SMSC barriers influence each other). In addition, HISA focuses on attenuation of influence without always quantifying these relationships. This integration enables a more holistic analysis of the system, considering both structural and functional aspects. It can provide valuable insights for decision-making processes. By understanding the hierarchical relationships and causal dependencies among SMSC barriers, decision-makers can gain a clearer understanding of the consequences of their choices and make more informed decisions.

In summary, TISM-DEMATEL's combination of quantification, handling of feedback loops, integration of expert judgment, visual representation, and comprehensive analysis makes it a more versatile and advanced methodology compared to ISM, DEMATEL, HISA etc. When it comes to understanding complex systems and their interdependencies.

Therefore, the objectives of the study are as follows:

(i) To identify and analyze the barriers to the implementation of SMSC by creating a database through literature review and semi-structured interviews with experts of the company and academicians.
(ii) To understand the interrelationships among these barriers that are extremely important for SMSC adoption.
(iii) To rank the identified barriers for the proper resolution of the issue.

The objectives include a contribution to the extant literature by analyzing the influential relationship and power of each barrier and supporting the adoption of SMSC. From the above discussion, the research questions are as follows:

RQ1: What barriers do manufacturers face for sustainable collaboration with suppliers?
RQ2: What are the most influential barriers for sustainable collaboration with suppliers?
RQ3: What managerial strategies can be applied to overcome the effects of identified barriers?

To address the research question, a novel solution methodology is proposed to identify and analyze SMSC barriers. To present the real-life application of the proposed solution methodology, a case example of a home appliances company based in India is presented. The case company is looking for SMSC barriers, seeking to build a structural model to better understand the SMSC barriers, and targeting to overcome SMSC barriers in order to implement sustainable supplier collaboration. The analysis of the SMSC barriers is a MCDM problem due to multiple barriers. Hence, this study utilizes TISM-DEMATEL to build an intelligent decision-making model to analyze SMSC barriers.

The rest of the paper is structured as follows: Section 2 offers a literature review on sustainable manufacturer-supplier collaboration. The problem description is discussed in Section 3. Further, a solution methodology is presented in the next section. Section 5 presents the real-life implication of the proposed solution methodology. Results are discussed in Section 6. The managerial implication of the current work is

shown in Section 7. Our conclusion, limitations, and future scope of the work are presented in the final section.

2. Literature review

This section presents an overview of the relevant literature in the line with discussed research questions. This section explores the literature on sustainable manufacturer-supplier collaboration, multi criteria decision making methods, and the research gap.

2.1. Sustainable manufacturer-supplier collaboration

The topic of manufacturer-supplier collaboration and sustainability has garnered significant interest among academics and practitioners, as evidenced by the growing body of literature (Chen et al., 2017). Sustainable manufacturer-supplier collaboration refers to the cooperation between manufacturing companies and their suppliers for sustainable initiatives. Scholars such as JS et al. (2019) highlight the importance of supply chain relationships, trust, information sharing quality, and technological involvement in achieving successful collaborative techniques. Effective collaboration among supply chain partners enhances operational effectiveness and leads to increased business turnovers. Chi et al. (2020) provide a comprehensive perspective on the drivers of effective collaboration within supply chains, emphasizing the significance of formal contracts, e-business strategic alignment, and competition in fostering collaboration. Feng et al. (2020) suggest incorporating green supplier collaboration to enhance the performance of manufacturing companies. Ukko et al. (2022) explore how supplier collaboration enables small-scale manufacturers to develop sustainability and achieve long-term competitiveness. Ahmed et al. (2020) emphasize the adoption of green practices and collaboration with suppliers and customers to generate a holistic impact, ultimately improving overall sustainability performance. Lozano et al. (2021) discuss the role of supplier collaboration in helping manufacturing companies become more sustainable. Govindan et al. (2021) underscore the importance of understanding supplier performance measures to initiate sustainable manufacturer-supplier collaboration. Khurshid et al. (2021) investigate the significance of collaborating with environmentally and socially responsible suppliers to enhance competitive advantage and maintain the legitimacy of manufacturing companies. Lo et al. (2022) contribute to the field of collaboration research by establishing assessment criteria, identifying key criteria, and providing supplier selection practices. The collective body of literature discussed above demonstrates the growing interest in sustainable manufacturer-supplier collaboration and sheds light on various aspects, including the drivers, performance measures, green practices, and supplier selection. A number of papers for sustainable manufacturer-supplier collaboration are available in the literature. However, actual sustainable manufacturer-supplier collaboration implementation is limited. This is because companies face a range of barriers in actual sustainable manufacturer-supplier collaboration implementation. Once that gap is recognized, it is imperative that manufacturers and suppliers should examine the barriers that underscore sustainable manufacturer-supplier collaboration. Hence, in this study, an extensive work is done in this area by identifying and analyzing the barriers to the SMSC implementation.

2.2. Multicriteria decision making methods for analysis of barriers

During the implementation of Sustainable Manufacturing Supply Chain (SMSC), companies encounter a variety of barriers that require a comprehensive decision-making approach to find effective solutions. Multicriteria Decision Making (MCDM) methods offer a suitable and holistic approach for strategic decision-making in barrier analysis. In the literature, researchers have applied various MCDM methods to analyze these barriers.

For instance, Alora and Barua (2019) utilized the Analytic Hierarchy Process (AHP) to prioritize and rank the barriers to supply chain finance adoption in manufacturing companies. Kumar et al. (2021) employed Modified Stepwise Weight Assessment Ratio Analysis and Weighted Sum Product Assessment Method to overcome barriers in the implementation of Industry 4.0. Jena and Dwivedi (2021) developed an integrated approach combining Interpretative Structural Modelling (ISM) and Decision-making Trial and Evaluation Laboratory (DEMATEL) to prioritize critical barriers to tourism growth in an Indian context. Kannan et al. (2022) used the Best Worst Method (BWM) and DEMATEL to estimate the weights of barriers related to the implementation of carbon regulatory environmental policies in the manufacturing supply chain. Additionally, Badri Ahmadi et al. (2022) proposed a criteria decision framework using the Z-based DEMATEL technique to investigate the interactions among environmental sustainability innovation criteria in the context of an emerging economy's manufacturing sector.

However, merely knowing the weights and rankings of barriers is insufficient. It is crucial to understand the reasons behind the occurrence of these barriers. To address this issue, this study employs an integrated approach combining Total Interpretive Structural Modelling (TISM) and DEMATEL for barrier analysis in SMSC. This approach allows for a deeper understanding of the interrelationships and causal factors associated with the barriers, enabling more effective strategies for overcoming them.

2.3. Research gap

From the discussed literature, it can be noted that significant research work has been done in sustainable manufacturer-supplier collaboration across various fields to achieve the competitive advantage in the market. To the best of our knowledge and belief, this work is the first attempt to identify and analyze barriers to the implementation of SMSC in a home appliance company in Indian context. To model the challenges for establishing their mutual influences, the reasons for these influences, the intensity of these influences, and for determining the barriers having high influential power, an integrated TISM-DEMATEL methodology, along with MICMAC analysis, is applied. This work aims to help managers in formulating coping strategies for effective abolition of the SMSC barriers so they can gain a competitive edge in the market.

3. Case study and problems

Achieving a sustainable supplier collaboration is essential for manufacturing companies to gain a competitive edge in the market. Suppliers play a critical role in delivering significant economic, environmental, and social benefits to the company. They contribute to the development of an efficient state-of-the-art infrastructure, provide access to valuable resources, and introduce new technologies that enhance the company's operations and products. Collaborating with suppliers who share the same structures, strategies, and cultures aligned with the company's goals and values is a challenging task.

When implementing a sustainable supplier collaboration, companies encounter various barriers, which can be classified as internal, external, technical, or non-technical. These barriers are not isolated but interconnected, making their resolution complex and challenging. The presence of these barriers creates a daunting challenge for managers when making strategic decisions for the company. To address these challenges effectively, manufacturing companies need to gain a clear understanding of the barriers and their interrelationships. This understanding allows them to develop appropriate strategic plans that consider the multifaceted and interconnected nature of the barriers.

To assist manufacturing companies in overcoming these barriers, this paper proposes a solution methodology that approaches the issue as a Multiple Criteria Decision Making (MCDM) problem. By treating it as such, the methodology provides a structured framework for evaluating and addressing the barriers to sustainable supplier collaboration. In this study, the case of an Indian home appliances manufacturing company

and its suppliers is considered as an illustrative example. The company, being a prominent player in the home appliances industry, produces a wide range of products, including air conditioners, dishwashers, washing machines, refrigerators, toasters, kettles, kitchen stoves, and microwaves.

Recognizing the potential negative environmental and societal impacts associated with the production of these products, the company aims to collaborate with its suppliers from a sustainable perspective. By working closely with suppliers, the company seeks to incorporate sustainability principles into its supply chain, thereby gaining a competitive advantage in the market. Before establishing sustainable collaboration with suppliers, the company acknowledges the importance of understanding and overcoming the barriers that may arise in the process. This understanding is crucial to enhance the overall performance of the manufacturer and its suppliers.

Therefore, the proposed solution methodology provides a comprehensive approach to analyzing and mitigating the barriers to sustainable supplier collaboration. By applying the MCDM framework, manufacturing companies can make informed decisions, optimize their collaboration efforts, and navigate the complexities associated with sustainable supplier collaboration. The detailed discussion and application of this solution methodology, specifically tailored for the case of the Indian home appliances manufacturing company and its suppliers, are presented in the subsequent sections of the paper.

4. Solution methodology

To achieve the objectives of this study, a novel solution methodology is proposed. This methodology is divided into three stages. In the first stage, key barriers to SMSC are identified based on the extant literature review and experts' opinions. TISM enables the identification of interrelationships among the SMSCs and establishes a multi-level hierarchical structure for them. TISM is then applied to develop a hierarchical structure to explain the direct and transitive links in a graph. A MICMAC analysis assists in determining the driving and dependence powers of the SMSCs, which can empower stakeholders to make well-informed decisions in the second stage. Note that TISM cannot determine the strength of relationships among SMSC barriers. Hence, DEMATEL is utilized to find the strength of relationships among SMSC barriers in third stage.

Let S be the system with k key performance indicators, i.e., $S = s_1, s_2, \ldots, s_k$ and D be the number of decision makers to provide their opinions.

The detailed procedure and steps of TISM and DEMATEL are explained below.

4.1. TISM

TISM is derived from Interpretive Structural Modelling (ISM). TISM is used to build a hierarchical structure of the identified SMSC barriers. TISM is an interpretive method that helps in understanding the contextual relationship between each pair of SMSC barriers and the direction of their relationship. Also, TISM overcomes the limitations of ISM by explaining the logic of relationships. These explanations are useful in tackling upcoming future challenges the experts may face. In summary, TISM provides answers not only for the 'what' and 'how' of the relationship among SMSC barriers; it also gives clarity about the 'why' of the relationship. TISM is a widely applied tool for identifying the prominent contextual relationship among barriers (Rajesh, 2017). The detailed steps of TISM are elaborated as follows:

Step 1: *Establish contextual relationship among SMSC barriers*

Experts are asked to provide their judgments regarding the relationship between two SMSC barriers (i and j) in order to find the contextual relationship within each barrier. For example, if SMSC barrier i is influencing SMSC barrier j, then '1' is entered into initial reachability matrix X; otherwise '0' is entered.

Step 2: *Interpretation of contextual relationship among SMSC barriers*

Further, the entries with value '1' in the initial reachability matrix of paired SMSC barriers are interpreted. These interpretations are helpful in explaining the exhaustive knowledge regarding identified barriers.

Step 3: *Check transitivity and derive final reachability matrix*

The final reachability matrix Y is derived by checking the transitivity. The basic concept of transitivity is if i^{th} SMSC barrier and j^{th} SMSC barrier are related and i^{th} SMSC barrier is related to another k^{th} SMSC barrier, then it indicates that j^{th} SMSC barrier is necessarily related to k^{th} SMSC barrier. All the entries with value '0' are checked for transitivity. If transitivity is present, the value '0' is replaced by '1'.

Step 4: *Partition the final reachability matrix into levels*

In this step, the partition of final reachability matrix Y is done based on three sets. These include the reachability set, antecedent set, and intersection set. The set of row elements of final reachability matrix that influence other SMSC barriers and itself is called the reachability set of SMSC barriers. Secondly, the antecedent set of SMSC barriers is the set of column elements of final reachability matrix that influence itself and other SMSC barriers. The common elements from reachability set and antecedent set define the intersection set. Further, the final reachability matrix is categorized into different levels, based on the reachability and antecedent sets, to get the importance level of each SMSC barrier.

Step 5: *Prepare a diagraph plot and Generate TISM model*

Using the contextual relationship among SMSC barriers, diagraphs are plotted to represent the most significant influence relations. Also, all the transitive links are identified and represented in the diagraphs. Next, a binary matrix is developed to translate the final diagraph. The cell with entry '1' depicts direct and significant transitive links, and the cell with entry '0' represents no connections. Also, causal thinking behind the direct and significant transitive links is presented in the form of an interpretive matrix.

The TISM model is derived from the information collected from interaction matrix and diagraph. The TISM model is drawn while discussing and presenting the reasons behind the direct and significant transitive links.

4.2. MICMAC analysis

MICMAC analysis is performed to group the SMSC barriers as per their driving and dependence powers. A graph is plotted with dependence power and driving power of SMSC barriers on x axis and y axis, respectively. These barriers are classified into four clusters as follows:

Autonomous Factors: The first cluster of the SMSC barriers has weak dependence power and weak driving power.

Dependence Factors: The second cluster of SMSC barriers has strong dependence power and weak driving power.

Linkage Factors: The third cluster consists of SMSC barriers with strong dependence and strong driving power.

Driving Factors: The SMSC barriers that lie in the fourth cluster have weak dependence power but a strong driving power.

4.3. DEMATEL

Decision-making trial and evaluation laboratory (DEMATEL) method was initially proposed by Geneva Research Centre of Battelle Memorial Institute in 1972. DEMATEL is utilized to investigate complex and

intertwined problems and to convert them into a structural model for visualizing complicated causal relationships. DEMATEL method addresses the interactions among SMSC barriers and categorizes them into either a cause or an effect group. Also, DEMATEL contributes to identifying feasible solutions in a hierarchical structured model (Xu et al., 2023). The explanatory steps of the DEMATEL method are discussed as follows:

Step 1: *Generate the initial direct-relation matrix*

Each decision maker is asked to indicate the influence of each SMSC barrier on each of the others according to a pairwise comparison scale given as follows: '0' – no influence, '1' – low influence, '2' – medium influence, '3' – high influence, '4' – very high influence. The initial direct relation matrix P, $k \times k$ matrix, is obtained by pairwise comparisons as per influences and directions between SMSC barriers given by each decision maker where p_{ij} represents the degree to which the SMSC barrier i influences the SMSC barrier j, i.e., $P = [p_{ij}]_{k\times k}$. As there are D decision makers, P^1, P^2, P^3, …, a P^D direct relation matrix is established.

Step 2: *Compute the average direct-relation matrix*

To aggregate all the opinions from D decision makers, the average direct-relation matrix $Q = [q_{ij}]_{k\times k}$ is computed as follows:

$$q_{ij} = \frac{1}{D}\sum_{d=1}^{D} p_{ij}^{d} \tag{1}$$

Step 3: *Normalize the average direct-relation matrix*

The normalized direct-relation matrix Z is calculated by using the following formula:

$$S = Q \times L \tag{2}$$

$$\text{where} L = \frac{1}{\max\limits_{1\le i\le k}\sum\limits_{j=1}^{k} y_{ij}}.i,j = 1,2,\ldots,k \tag{3}$$

Step 4: *Determine the total relation matrix*

The total relation matrix T is acquired by using the following formula:

$$T = S(I-S)^{-1} \tag{4}$$

Where I is denoted as the identity matrix.

Step 5: *Calculate the sum of rows and columns*

Let r and c be the sum of rows and sum of columns of total relation matrix T respectively and are computed as follows:

$$T = t_{ij}, i,j = 1,2,\ldots,k. \tag{5}$$

$$r = \left[\sum_{j=1}^{k} t_{ij}\right]_{k\times 1} \tag{6}$$

$$c = \left[\sum_{j=1}^{k} t_{ij}\right]_{1\times k} \tag{7}$$

Where r represents both direct and indirect effects of SMSC barrier i to the other SMSC barriers and c represents both direct and indirect effects by SMSC barrier j from the other SMSC barriers. When $j = i$, the sum $(r + c)$ portrays the degree of importance that SMSC barrier i has in the entire system. On the contrary, difference $(r - c)$ shows the net effect that SMSC barrier i has in the entire system. If $(r - c) > 0$, SMSC barrier i is a net cause and if $(r - c) < 0$, SMSC barrier i is a net receiver.

Step 6: *Construct cause-effect relationship diagram*

A cause-effect relationship diagram is constructed based on $(r + c)$ and $(r - c)$ values. The dataset of $(r + c, r - c)$ is mapped to acquire the relationship diagram where horizontal axis and vertical axis are $(r + c)$ and $(r - c)$ respectively.

5. Implementation of solution methodology

A case study of an Indian home appliances manufacturing company is considered in this study to validate the proposed solution methodology. This section includes the process of identifying SMSC barriers and data analysis by utilizing integrated TISM-DEMATEL approach.

5.1. Identification of SMSC barriers

A team of experts is formed to analyze the discussed problem. The experts come from various functions: planning, general administration, production, quality, and environment. These experts have more than 10 years of industrial experience and have excellent skills in decision making. Details of each expert's role and years of experience are provided in Table 1.

After extensive literature review and discussion with these experts, the SMSC barriers are finalized as shown in Table 2.

5.2. TISM analysis

After identifying the SMSC barriers, decision-making team is asked to develop contextual relationship among SMSC barriers for developing the initial reachability matrix. The SMSC barriers, contextual relationship, and their interrelationship are presented in Table A1. With the help of experts, the relationship between two SMSC barriers (i and j) are

Table 1
Experts with their background and year of experience.

S. No.	Expert	Role	Year of experience
1	Planning Expert	Represents the strategic viewpoint and ensures that the problem of sustainable supplier-manufacturer collaboration is analyzed and addressed in alignment with long-term organizational goals and sustainability objectives.	15
2	General administration Expert	Represents the administrative perspective and ensures effective coordination and communication between suppliers and the manufacturing company, facilitating sustainable collaboration.	17
3	Production Expert	Represents the production function and ensures that sustainable practices and considerations are integrated into manufacturing processes, optimizing resource utilization, and minimizing environmental impact.	14
4	Quality Expert	Represents the quality assurance aspect and ensures that sustainable supplier-manufacturer collaboration is upheld by maintaining and improving product quality while adhering to sustainability standards.	11
5	Environment Expert	Represents the environmental viewpoint and ensures that sustainable supplier-manufacturer collaboration is assessed in terms of its ecological impact, promoting environmentally friendly practices, and fostering eco-conscious decision-making.	19

Table 2
Barriers to sustainable manufacturer-supplier collaboration.

S. No.	Barrier	Notation	Definition	Reference
1	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations	B_1^{SMSC}	Restricted information flow between the manufacturer and supplier. Efficacious communication of sustainable goals with their suppliers is required for providing a clear picture to suppliers how these sustainable goals are linked with their regular functions.	Shalique et al. (2021), Fan and Stevenson (2018)
2	Poor sustainability credibility of manufacturer as perceived by their suppliers	B_2^{SMSC}	Lack of credibility towards social and environmental aspects of manufacturer in the eyes of their suppliers. The manufacturer's practices such as frequent supplier switching, 'loss of business' trick for bargaining, inflexible specifications, misuse of power by quality authorities, price-oriented buying increase the credibility gap.	Lascelles and Dale (1989), Moon and Tikoo (2003), Hidayat et al. (2015)
3	Lack of trust between manufacturer and supplier	B_3^{SMSC}	Non frequent, short-term interaction and opportunistic behavior between manufacturer and supplier create trust issues between them.	Ryu et al. (2008), Butt et al. (2020)
4	Misaligned practices for pollution prevention between manufacturer and supplier	B_4^{SMSC}	Lack of alignment in pollution reduction and elimination practices between manufacturer and supplier. Misalignment of practices that help in pollution prevention negatively impacts the environment and creates a difference between manufacturer and supplier.	Wong et al. (2012), Govindan et al. (2021 a)
5	Lack of joint planning to manage the environmental management system	B_5^{SMSC}	Non-coordinated actions between manufacturer and supplier for reducing environmental objectives and targets. Desynchronized practices and processes of managing the environmental management system encounter many problems and conflicts with each other.	Vachon and Klassen (2008), Wong et al. (2015), Chen and Ye (2020)
6	Lack of coordination for pollution controls between suppliers and manufacturer	B_6^{SMSC}	Asynchronism in techniques for controlling the amount of pollution releases to the environment by the supplier and manufacturer. Ineffective coordination between manufacturer and supplier leads to manufacturer-supplier relationship dissolution.	Kim and Sim (2016), Kang et al. (2020)
7	Lack of scope and focus for sustainable collaboration	B_7^{SMSC}	Not having a clear vision for manufacturer-supplier collaboration. Lack of scope, focus and specified sustainable objectives of each other give only vague intentions rather than providing momentum to collaboration.	Wagner (2003), Skjoett-Larsen et al. (2003)
8	Fear of failure for sustainable collaboration adoption	B_8^{SMSC}	Manufacturer and supplier are afraid of failure while adopting the sustainable collaboration because it could fail at many levels, including monetary loss or product failure, that especially hampers their market reputation.	Howard et al. (2003), Govindan et al. (2014)
9	Unwillingness to share risks and rewards	B_9^{SMSC}	Facing challenges in risk and reward sharing practices of sustainability during collaboration. These challenges are the results of goal conflicts between manufacturer and supplier.	Ramesh et al. (2010), Yunus and Kurniawan (2015), Sharma et al. (2018)
10	Lack of collaborative efforts in return handling and waste material treatment	B_{10}^{SMSC}	Noncooperative activities or practices of manufacturer and supplier to handle the returns and waste material. These activities can increase	Govindan et al. (2021); Kannan et al. (2024)

(*continued on next page*)

Table 2 (*continued*)

S. No.	Barrier	Notation	Definition	Reference
			environmental problems.	
11	Lack of synchronization in environmental competencies	B_{11}^{SMSC}	Misalignment in environment related competencies enables conflicts and disagreements between manufacturer and supplier.	Liu et al. (2013), Theiβen and Spinler (2014)
12	Lack of joint planning for recycling	B_{12}^{SMSC}	Non-aligned strategy to recycle used materials, components, or products that suppress the willingness of forming long term sustainable relationships.	Abdulrahman et al. (2014)
13	Lack of combined training programs	B_{13}^{SMSC}	Disjointed training programs to train, monitor, and mentor the employees of manufacturer and suppliers for adopting a sustainable supply chain system. Disjointed training may create different perspectives and training towards the concept of sustainability.	Oh and Rhee (2008), Patrucco et al. (2017)
14	Lack of collaborative actions for employment practices	B_{14}^{SMSC}	Unwillingness to do joint planning for employment practices like working hours, child labor, career development, employment compensation, and equity labor sources.	Alam et al. (2018), Govindan et al. (2021 a)
15	Lack of sharing responsibilities for interests and rights of employees	B_{15}^{SMSC}	Different mindset for promoting employee concerns related to sustainable employment issues.	Huq et al. (2016)
16	Lack of sharing responsibilities for worker health and safety	B_{16}^{SMSC}	Asynchronism in rules for their operation health and safety practices by the supplier and the manufacturer.	Ahmadi et al. (2017); Govindan et al. (2021 b)
17	Lack of joint planning to manage occupational health and safety management systems	B_{17}^{SMSC}	Non-coordinated actions between manufacturer and supplier for health, safety, and welfare of workers at workplace. Desynchronized practices and processes of managing the occupational health and safety management system encounter many problems and conflicts with each other.	Ahmadi et al. (2017)
18	Lack of top management involvement	B_{18}^{SMSC}	Reluctant behavior of top management of both manufacturer and supplier to adopt sustainable collaboration.	Tarigan et al. (2020)
19	Lack of a consistent and adequate performance measurement system	B_{19}^{SMSC}	Inconsistent and inadequate performance metrics for integrated manufacturer supplier work management systems.	Ramesh et al. (2010), Maestrini et al. (2018)

recorded in order to find the contextual relationship within each barrier and to form an initial reachability matrix as presented in Table A2. In this study, the contextual relationship is termed 'SMSC barrier A will influence SMSC barrier B' and the interpretative logic is defined as 'How or in what way will SMSC barrier A influence SMSC barrier B?'. As 19 SMSC barriers are considered, the total number of rows of interpretation is 19*18 = 342. The interpretation logic is discussed and filled with decision making team as presented in Table A3. After that, transitivity is checked in the initial reachability matrix and the final reachability matrix is achieved by considering the significant transitive links as shown in Table A4. The interpretation of transitive links is shown in Table A5. Later, the reachability and antecedent sets for each SMSC barrier are derived from the final reachability matrix, and level partitioning is done as presented in Tables A.6, A.7, A.8, A.9, and A.10. All the partition matrices are summarized and shown in Table 3. With the

Table 3
Summary of level partition matrix.

Notation	Barrier	Level
B_8^{SMSC}	Fear of failure for sustainable collaboration adoption	I
B_2^{SMSC}	Poor sustainability credibility of manufacturer as perceived by their suppliers	II
B_4^{SMSC}	Misaligned practices for pollution prevention between manufacturer and supplier	II
B_{10}^{SMSC}	Lack of collaborative efforts in return handling and waste material treatment	II
B_{11}^{SMSC}	Lack of synchronization in environmental competencies	II
B_{12}^{SMSC}	Lack of joint planning for recycling	II
B_5^{SMSC}	Lack of joint planning to manage the environmental management system	III
B_6^{SMSC}	Lack of coordination for pollution controls between suppliers and manufacturer	III
B_{14}^{SMSC}	Lack of collaborative actions for employment practices	III
B_{15}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees	III
B_{16}^{SMSC}	Lack of sharing responsibilities for worker health and safety	III
B_{17}^{SMSC}	Lack of joint planning to manage occupational health and safety management system	III
B_{13}^{SMSC}	Lack of combined training programs	IV
B_{19}^{SMSC}	Lack of consistent and adequate performance measurement system	IV
B_1^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations	V
B_3^{SMSC}	Lack of trust between manufacturer and supplier	V
B_7^{SMSC}	Lack of scope and focus for sustainable collaboration	V
B_9^{SMSC}	Unwillingness to share risks and rewards	V
B_{18}^{SMSC}	Lack of top management involvement	V

Table 4
Average direct relationship matrix for SMSC barriers.

	B_1^{SMSC}	B_2^{SMSC}	B_3^{SMSC}	B_4^{SMSC}	B_5^{SMSC}	B_6^{SMSC}	B_7^{SMSC}	B_8^{SMSC}	B_9^{SMSC}	B_{10}^{SMSC}	B_{11}^{SMSC}	B_{12}^{SMSC}	B_{13}^{SMSC}	B_{14}^{SMSC}	B_{15}^{SMSC}	B_{16}^{SMSC}	B_{17}^{SMSC}	B_{18}^{SMSC}	B_{19}^{SMSC}
B_1^{SMSC}	0,00	2,67	3,00	3,33	2,67	2,67	3,33	3,00	3,00	4,00	3,00	2,33	3,33	3,33	3,67	3,67	3,00	4,00	3,00
B_2^{SMSC}	0,00	0,00	0,00	3,00	1,00	1,00	3,00	3,67	2,67	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00
B_3^{SMSC}	3,00	4,00	0,00	1,00	1,00	1,00	1,00	3,00	3,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
B_4^{SMSC}	0,00	3,33	0,00	0,00	3,00	3,00	1,00	2,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_5^{SMSC}	0,00	3,67	0,00	3,00	0,00	2,00	1,00	3,00	1,00	4,00	3,00	2,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_6^{SMSC}	0,00	4,00	0,00	4,00	3,00	0,00	1,00	2,67	1,00	1,00	1,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_7^{SMSC}	1,00	3,00	4,00	2,00	4,00	3,00	0,00	3,00	2,67	2,00	3,00	2,33	4,00	3,00	2,00	3,00	4,00	1,00	3,00
B_8^{SMSC}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_9^{SMSC}	3,00	1,00	1,00	2,00	2,00	2,00	1,00	3,33	0,00	4,00	4,00	4,00	2,00	4,00	4,00	3,00	3,00	1,00	1,00
B_{10}^{SMSC}	0,00	2,50	0,00	1,00	0,00	0,00	1,00	2,17	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{11}^{SMSC}	0,00	4,00	0,00	1,00	0,00	0,00	1,00	3,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{12}^{SMSC}	0,00	3,00	0,00	1,00	3,00	1,00	1,00	3,17	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{13}^{SMSC}	0,00	4,00	0,00	4,00	4,00	3,00	1,00	3,33	1,00	3,00	3,00	2,00	0,00	3,00	4,00	4,00	3,00	1,00	2,00
B_{14}^{SMSC}	0,00	3,00	0,00	1,00	0,00	0,00	1,00	3,67	1,00	0,00	0,00	0,00	0,00	0,00	4,00	3,00	3,00	0,00	0,00
B_{15}^{SMSC}	0,00	2,50	0,00	1,00	0,00	0,00	1,00	3,33	1,00	0,00	0,00	0,00	0,00	3,00	0,00	2,00	2,00	0,00	0,00
B_{16}^{SMSC}	0,00	3,50	0,00	1,00	0,00	0,00	1,00	3,00	1,00	0,00	0,00	0,00	0,00	4,00	4,00	0,00	4,00	0,00	0,00
B_{17}^{SMSC}	0,00	4,00	0,00	1,00	0,00	0,00	1,00	4,00	1,00	0,00	0,00	0,00	0,00	3,33	3,00	3,67	0,00	0,00	0,00
B_{18}^{SMSC}	3,00	4,00	2,00	2,00	4,00	4,00	3,00	3,00	3,00	2,00	3,00	4,00	3,00	2,00	4,00	3,33	3,00	0,00	3,67
B_{19}^{SMSC}	1,00	1,00	0,00	3,00	2,50	3,50	0,00	4,00	0,00	3,00	2,00	3,00	4,00	3,00	2,67	4,00	2,00	0,00	0,00

Table 5
Normalized direct relationship matrix for SMSC barriers.

	B_1^{SMSC}	B_2^{SMSC}	B_3^{SMSC}	B_4^{SMSC}	B_5^{SMSC}	B_6^{SMSC}	B_7^{SMSC}	B_8^{SMSC}	B_9^{SMSC}	B_{10}^{SMSC}	B_{11}^{SMSC}	B_{12}^{SMSC}	B_{13}^{SMSC}	B_{14}^{SMSC}	B_{15}^{SMSC}	B_{16}^{SMSC}	B_{17}^{SMSC}	B_{18}^{SMSC}	B_{19}^{SMSC}
B_1^{SMSC}	0,00	0,05	0,05	0,06	0,05	0,05	0,06	0,05	0,05	0,07	0,05	0,04	0,06	0,06	0,06	0,06	0,05	0,07	0,05
B_2^{SMSC}	0,00	0,00	0,00	0,05	0,02	0,02	0,05	0,06	0,05	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,00	0,02
B_3^{SMSC}	0,05	0,07	0,00	0,02	0,02	0,02	0,02	0,05	0,05	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
B_4^{SMSC}	0,00	0,06	0,00	0,00	0,05	0,05	0,02	0,04	0,02	0,02	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_5^{SMSC}	0,00	0,06	0,00	0,05	0,00	0,04	0,02	0,05	0,02	0,07	0,05	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_6^{SMSC}	0,00	0,07	0,00	0,07	0,05	0,00	0,02	0,05	0,02	0,02	0,02	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_7^{SMSC}	0,02	0,05	0,07	0,04	0,07	0,05	0,00	0,05	0,05	0,04	0,05	0,04	0,07	0,05	0,04	0,05	0,07	0,02	0,05
B_8^{SMSC}	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_9^{SMSC}	0,05	0,02	0,02	0,04	0,04	0,04	0,02	0,06	0,00	0,07	0,07	0,07	0,04	0,07	0,07	0,05	0,05	0,02	0,02
B_{10}^{SMSC}	0,00	0,04	0,00	0,02	0,00	0,00	0,02	0,04	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{11}^{SMSC}	0,00	0,07	0,00	0,02	0,00	0,00	0,02	0,05	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{12}^{SMSC}	0,00	0,05	0,00	0,02	0,05	0,02	0,02	0,06	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
B_{13}^{SMSC}	0,00	0,07	0,00	0,07	0,07	0,05	0,02	0,06	0,02	0,05	0,05	0,04	0,00	0,05	0,07	0,07	0,05	0,02	0,04
B_{14}^{SMSC}	0,00	0,05	0,00	0,02	0,00	0,00	0,02	0,06	0,02	0,00	0,00	0,00	0,00	0,00	0,07	0,05	0,05	0,00	0,00
B_{15}^{SMSC}	0,00	0,04	0,00	0,02	0,00	0,00	0,02	0,06	0,02	0,00	0,00	0,00	0,00	0,05	0,00	0,04	0,04	0,00	0,00
B_{16}^{SMSC}	0,00	0,06	0,00	0,02	0,00	0,00	0,02	0,05	0,02	0,00	0,00	0,00	0,00	0,07	0,07	0,00	0,07	0,00	0,00
B_{17}^{SMSC}	0,00	0,07	0,00	0,02	0,00	0,00	0,02	0,07	0,02	0,00	0,00	0,00	0,00	0,06	0,05	0,06	0,00	0,00	0,00
B_{18}^{SMSC}	0,05	0,07	0,04	0,04	0,07	0,07	0,05	0,05	0,05	0,04	0,05	0,07	0,05	0,04	0,07	0,06	0,05	0,00	0,06
B_{19}^{SMSC}	0,02	0,02	0,00	0,05	0,04	0,06	0,00	0,07	0,00	0,05	0,04	0,05	0,07	0,05	0,05	0,07	0,04	0,00	0,00

Table 6
Total relationship matrix for SMSC barriers.

	B_1^{SMSC}	B_2^{SMSC}	B_3^{SMSC}	B_4^{SMSC}	B_5^{SMSC}	B_6^{SMSC}	B_7^{SMSC}	B_8^{SMSC}	B_9^{SMSC}	B_{10}^{SMSC}	B_{11}^{SMSC}	B_{12}^{SMSC}	B_{13}^{SMSC}	B_{14}^{SMSC}	B_{15}^{SMSC}	B_{16}^{SMSC}	B_{17}^{SMSC}	B_{18}^{SMSC}	B_{19}^{SMSC}
B_1^{SMSC}	0,015	0127	0,064	0108	0,088	0083	0,091	0139	0,089	0104	0,087	0073	0,081	0104	0,112	0109	0,096	0077	0,071
B_2^{SMSC}	0,005	0029	0,006	0070	0,035	0032	0,063	0096	0,059	0032	0,032	0030	0,027	0035	0,035	0034	0,034	0003	0,024
B_3^{SMSC}	0,059	0104	0,008	0044	0,039	0036	0,037	0095	0,071	0038	0,037	0036	0,031	0041	0,043	0041	0,039	0024	0,028
B_4^{SMSC}	0,002	0076	0,003	0016	0,063	0061	0,027	0056	0,027	0028	0,027	0026	0,005	0006	0,006	0006	0,006	0001	0,004
B_5^{SMSC}	0,002	0087	0,003	0068	0,014	0045	0,029	0078	0,029	0078	0,061	0043	0,005	0007	0,007	0007	0,007	0001	0,004
B_6^{SMSC}	0,002	0089	0,003	0084	0,064	0012	0,028	0069	0,028	0029	0,028	0027	0,005	0007	0,007	0006	0,007	0001	0,004
B_7^{SMSC}	0,028	0121	0,076	0079	0,102	0081	0,028	0127	0,077	0066	0,081	0067	0,086	0090	0,075	0089	0,103	0024	0,065
B_8^{SMSC}	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000	0000	0,000
B_9^{SMSC}	0,058	0077	0,025	0069	0,061	0056	0,042	0121	0,026	0091	0,089	0087	0,047	0100	0,102	0083	0,081	0024	0,028
B_{10}^{SMSC}	0,002	0050	0,002	0024	0,005	0005	0,022	0048	0,022	0005	0,005	0004	0,004	0005	0,005	0005	0,005	0001	0,003
B_{11}^{SMSC}	0,002	0077	0,002	0025	0,006	0006	0,024	0065	0,024	0005	0,006	0005	0,004	0006	0,006	0005	0,006	0001	0,003
B_{12}^{SMSC}	0,002	0065	0,002	0029	0,060	0025	0,025	0071	0,025	0010	0,009	0007	0,004	0006	0,006	0005	0,006	0001	0,003
B_{13}^{SMSC}	0,005	0124	0,005	0103	0,093	0073	0,041	0119	0,041	0073	0,071	0052	0,011	0080	0,098	0095	0,078	0020	0,042
B_{14}^{SMSC}	0,002	0072	0,003	0029	0,007	0006	0,027	0090	0,028	0006	0,006	0006	0,005	0018	0,085	0066	0,066	0001	0,004
B_{15}^{SMSC}	0,002	0060	0,002	0027	0,006	0006	0,025	0079	0,026	0005	0,006	0005	0,004	0064	0,015	0047	0,047	0001	0,003
B_{16}^{SMSC}	0,002	0084	0,003	0031	0,008	0007	0,029	0082	0,029	0006	0,007	0006	0,005	0087	0,087	0019	0,085	0001	0,004
B_{17}^{SMSC}	0,002	0090	0,003	0030	0,008	0007	0,028	0097	0,029	0007	0,007	0006	0,005	0074	0,070	0077	0,018	0001	0,004
B_{18}^{SMSC}	0,063	0146	0,046	0088	0,110	0104	0,085	0138	0,088	0072	0,086	0100	0,075	0080	0,114	0101	0,092	0010	0,080
B_{19}^{SMSC}	0,019	0067	0,003	0082	0,066	0078	0,019	0119	0,019	0069	0,050	0065	0,075	0075	0,072	0091	0,057	0003	0,006

Table 7
Degree of influence for SMSC barriers.

	R	C	R + C	R–C	Cause/Effect
B_1^{SMSC}	1719	0,274	1994	1445	cause
B_2^{SMSC}	0,680	1544	2224	−0,864	effect
B_3^{SMSC}	0,852	0257	1109	0,595	cause
B_4^{SMSC}	0,446	1007	1453	−0,561	effect
B_5^{SMSC}	0,573	0836	1409	−0,263	effect
B_6^{SMSC}	0,500	0721	1220	−0,221	effect
B_7^{SMSC}	1464	0,669	2133	0,796	cause
B_8^{SMSC}	0,000	1689	1689	−1689	effect
B_9^{SMSC}	1270	0,738	2008	0,532	cause
B_{10}^{SMSC}	0,220	0723	0,943	−0,503	effect
B_{11}^{SMSC}	0,279	0695	0,974	−0,416	effect
B_{12}^{SMSC}	0,361	0648	1009	−0,286	effect
B_{13}^{SMSC}	1222	0,479	1701	0,743	cause
B_{14}^{SMSC}	0,527	0885	1412	−0,358	effect
B_{15}^{SMSC}	0,431	0942	1374	−0,511	effect
B_{16}^{SMSC}	0,581	0884	1465	−0,302	effect
B_{17}^{SMSC}	0,563	0831	1394	−0,268	effect
B_{18}^{SMSC}	1676	0,197	1874	1479	cause
B_{19}^{SMSC}	1034	0,381	1415	0,653	cause

help of contextual relationships, the diagraph is formed as presented in Fig. 1. Next, the interpretation of contextual relationship is substituted with node elements and diagraph is transformed into a TISM model with levels as shown in Figs. 2–4.

5.3. MICMAC analysis

After developing TISM model, MICMAC analysis is performed. The main aim of this analysis is to group the SMSC barriers as per their driving and dependence powers. The SMSC barriers are categorized into four groups. These groups as autonomous factors, dependence factors, linkage factors, and driving factors. The driving power and dependence power are computed for each SMSC barrier from Table A4. The SMSC barriers under autonomous category have weak dependence power and weak driving power. These SMSC barriers have no relation with the overall system. The SMSC barriers under dependence category have strong dependence power and weak driving power. In the linkage category, SMSC barriers have strong dependence and strong driving power. Finally, barriers with a weak dependence power but a strong driving power are called independent barriers. A graph is plotted to demonstrate the driving and dependence powers of barriers to complete the MICMAC analysis; it is shown in Fig. 5.

5.4. DEMATEL analysis

In this section, DEMATEL method is applied to find out the cause-and-effect relationship among the barriers of sustainable supplier manufacturer collaboration. Initially, the decision making team is asked to rate the SMSC barriers based on 0–4 scale. The pairwise comparison matrix is computed with respect to each decision maker's response. Later, average matrix is computed by aggregating the decision maker's response pairwise comparison matrices as shown in Table 4. Subsequently, Equations (2) and (3) are used to normalize the average matrix as presented in Table 5.

Next, the total relationship matrix is computed by using Equation (4), as shown in Table 6. With the help of total relationship matrix, r and c are computed. Later, prominence values (r + c) and relation values (r - c) are determined. The degree of influences is shown in Table 7.

Finally, the TISM model is integrated with the intensity of relationship among SMSC barriers i.e., computed by DEMATEL as shown in Fig. 6.

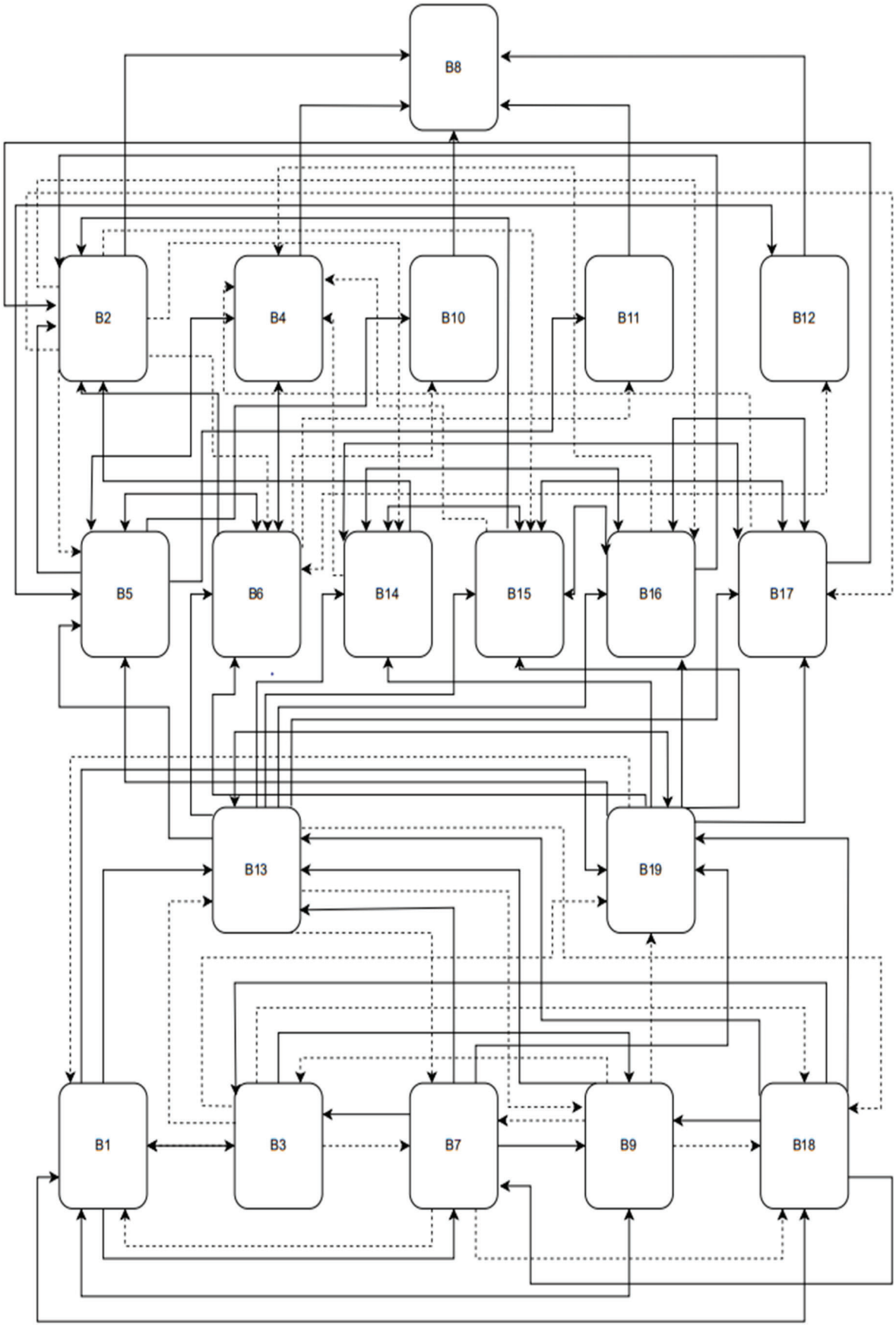

Fig. 1. Diagraph with significant transitive links.

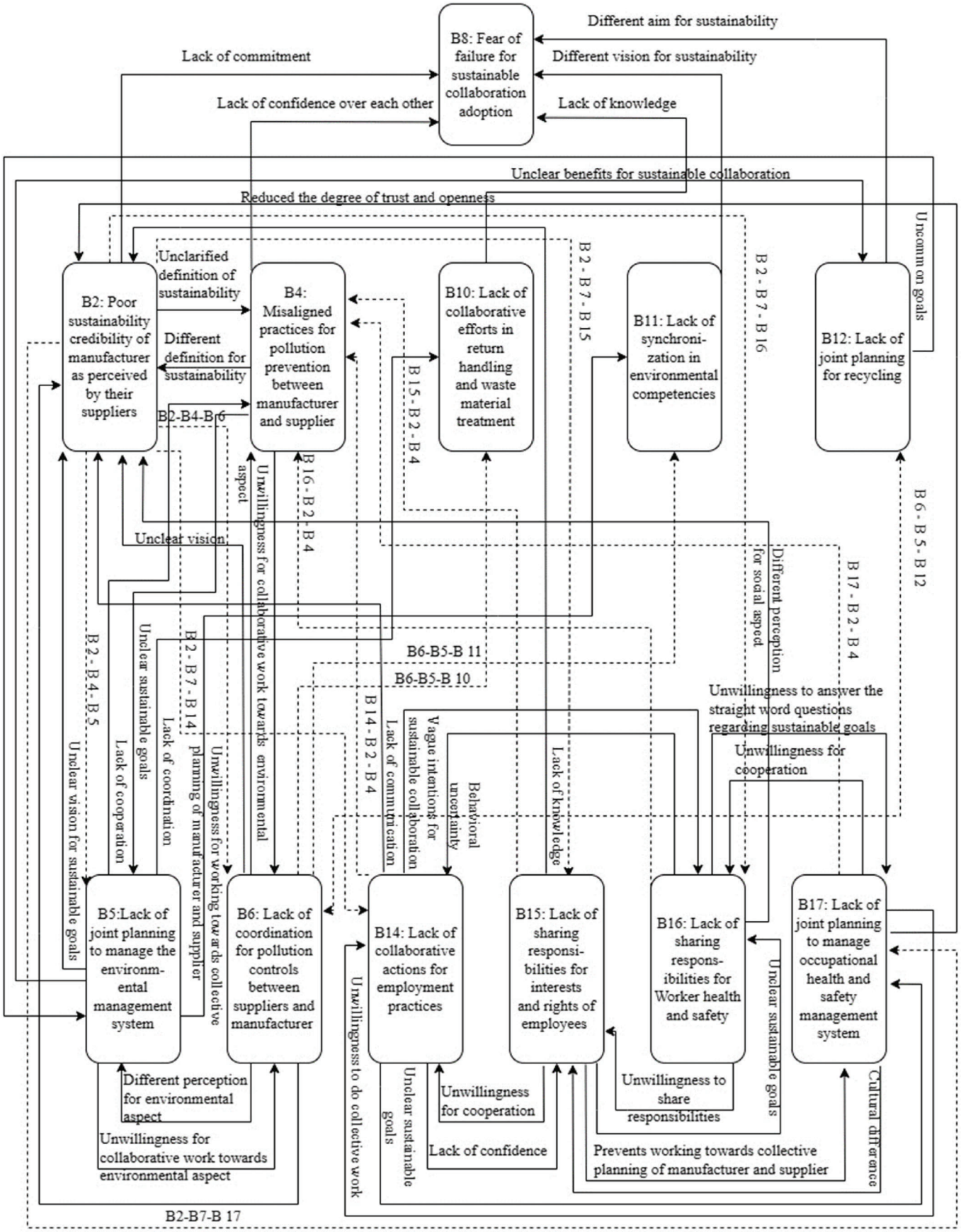

Fig. 2. TISM model with level I-II- III

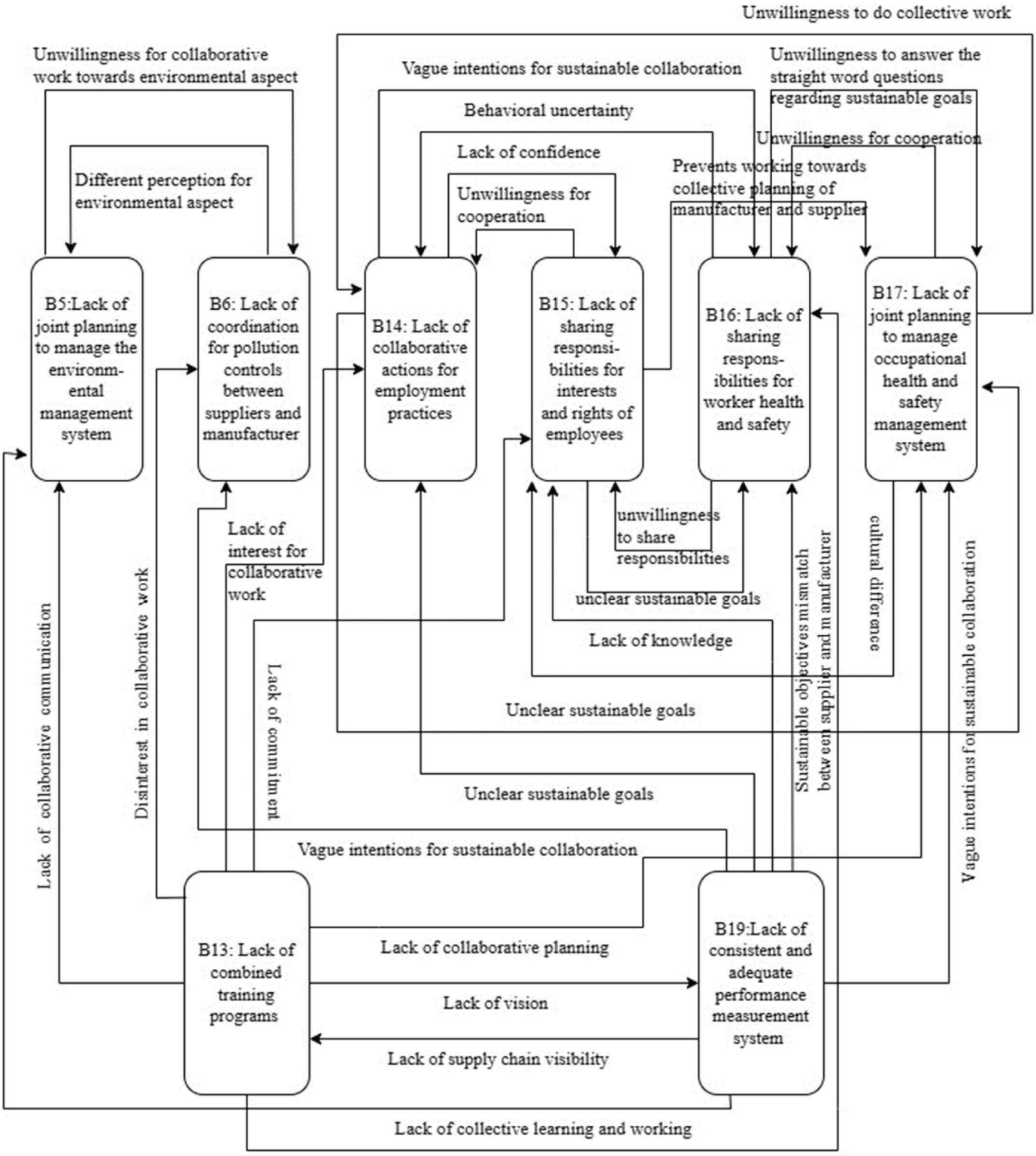

Fig. 3. TISM model with level III-level IV.

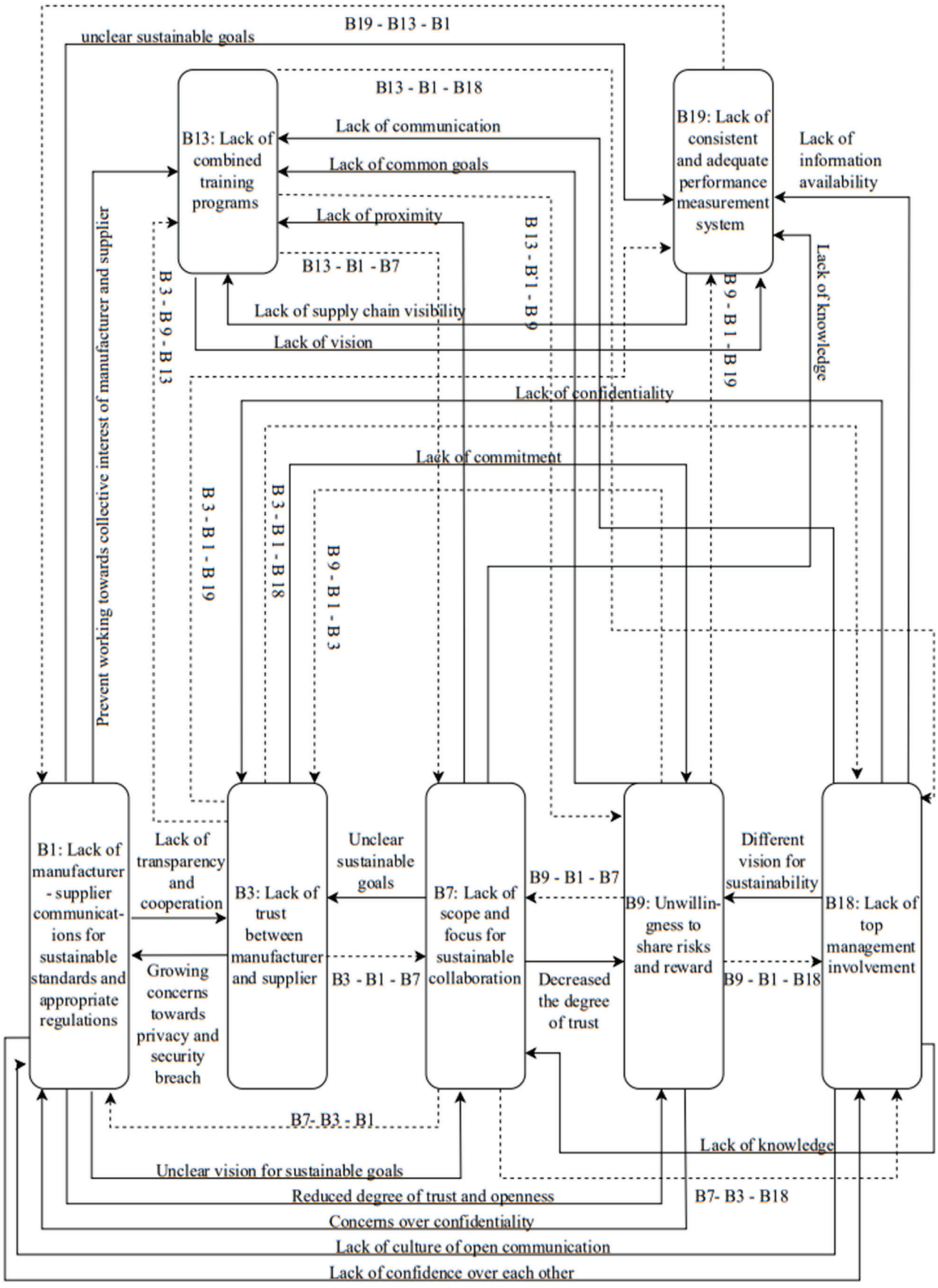

Fig. 4. TISM model with level IV-level V.

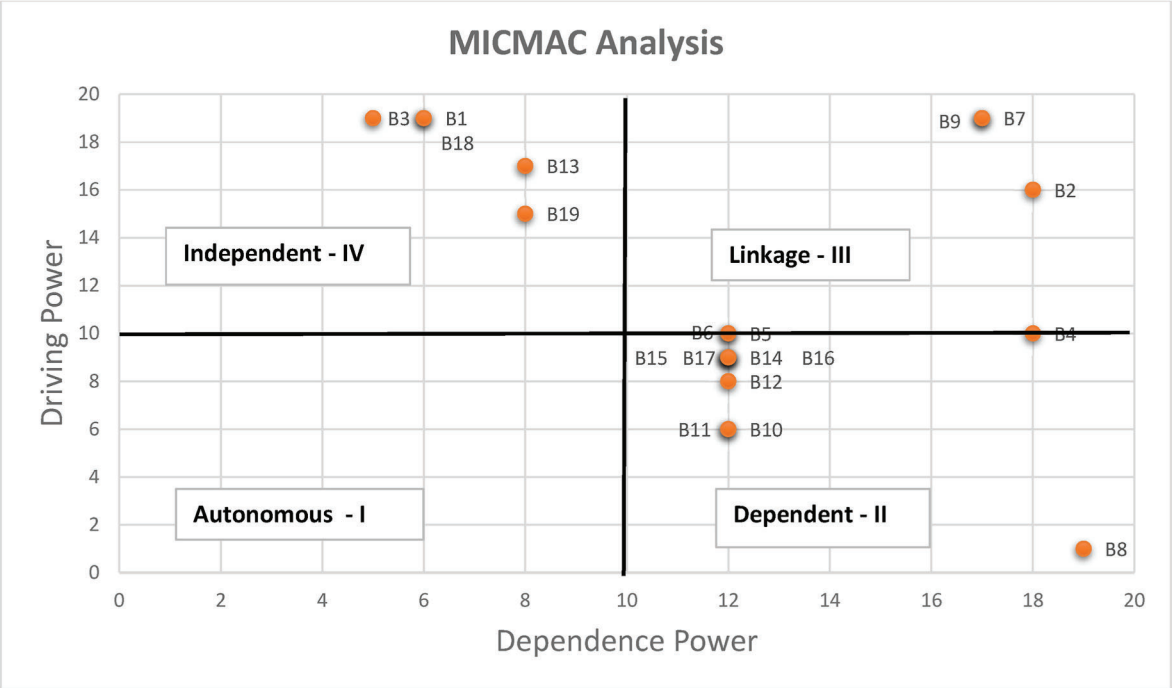

Fig. 5. MICMAC analysis.

6. Result discussion

The results of the study are discussed in this section as follows:

6.1. TISM results

The TISM analysis provides important information regarding the SMSC barriers for implementing a sustainable manufacturer-supplier collaboration. It helps in classifying the SMSC barriers into levels. In order, the topmost SMSC barriers in the hierarchy are less significant, the middle level is moderately significant, and the SMSC barriers in the bottom level are the most significant.

From the results of TISM analysis, at level I, fear of failure for sustainable collaboration adoption (B_8^{SMSC}) is the least significant barrier as it is found at the topmost level of the diagraph. This result demonstrates that this barrier is not a crucial SMSC barrier to the implementation of sustainable collaboration between manufacturer and supplier, but it can be influenced by other SMSC barriers that are more significant in SMSC implementation. Fear of failure for sustainable collaboration adoption can only limit and stifle the drive that is essential for SMSC implementation (Geng et al., 2020).

The middle level consists of eleven barriers from levels II and III, including poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}), misaligned practices for pollution prevention between manufacturer and supplier (B_4^{SMSC}), lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}), lack of synchronization in environmental competencies (B_{11}^{SMSC}), lack of joint planning for recycling (B_{12}^{SMSC}), lack of joint planning to manage the environmental management system (B_5^{SMSC}), lack of coordination for pollution controls between suppliers and manufacturer (B_6^{SMSC}), lack of collaborative actions for employment practices (B_{14}^{SMSC}), lack of sharing responsibilities for interests and rights of employees (B_{15}^{SMSC}), lack of sharing responsibilities for worker health and safety(B_{16}^{SMSC}) and lack of joint planning to manage occupational health and safety management system (B_{17}^{SMSC}). As manufacturer and supplier face challenges in implementing sustainable collaboration, poor sustainability credibility of manufacturer, as perceived by their suppliers, is considered one of the critical challenges of adopting SMSC. A manufacturer's lack of credibility towards social and environmental aspects might be perceived because of their business practices, such as frequent supplier switching, 'loss of business' trick for bargaining, inflexible specifications, misuse of power by quality authorities, or price-oriented buying (Hidayat et al., 2015). A misaligned practice for pollution prevention between manufacturer and supplier is another barrier that restricts the SMSC implementation; a lack of alignment in pollution reduction and elimination practices between manufacturer and supplier negatively impacts the environment and creates a difficult difference between manufacturer and supplier (Govindan et al., 2021 a). In addition to this, manufacturer and suppliers are deficient in collaborative efforts in return handling and waste material treatment, synchronization in environmental competencies, joint planning for recycling, joint planning to manage the environmental management system, coordination for pollution controls between suppliers and manufacturer, collaborative actions for employment practices, sharing responsibilities for interests and rights of employees, sharing responsibilities for worker health and safety, and joint planning to manage occupational health and safety management system that make the SMSC adoption process complex.

Level IV and level V are considered the bottom levels of the hierarchy. These levels include the seven most significant SMSC barriers: lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}), lack of trust between manufacturer and supplier (B_3^{SMSC}), lack of scope and focus for sustainable collaboration (B_7^{SMSC}), unwillingness to share risks and rewards (B_9^{SMSC}), lack of top management involvement (B_{18}^{SMSC}), lack of combined training programs (B_{13}^{SMSC}), and lack of consistent and adequate performance measurement system (B_{19}^{SMSC}). These critical SMSC barriers drive the other barriers that are positioned elsewhere. Hence, mitigation strategies for these most significant barriers can help to overcome not only these barriers but also other SMSC barriers at other levels. Mitigation strategies to overcome

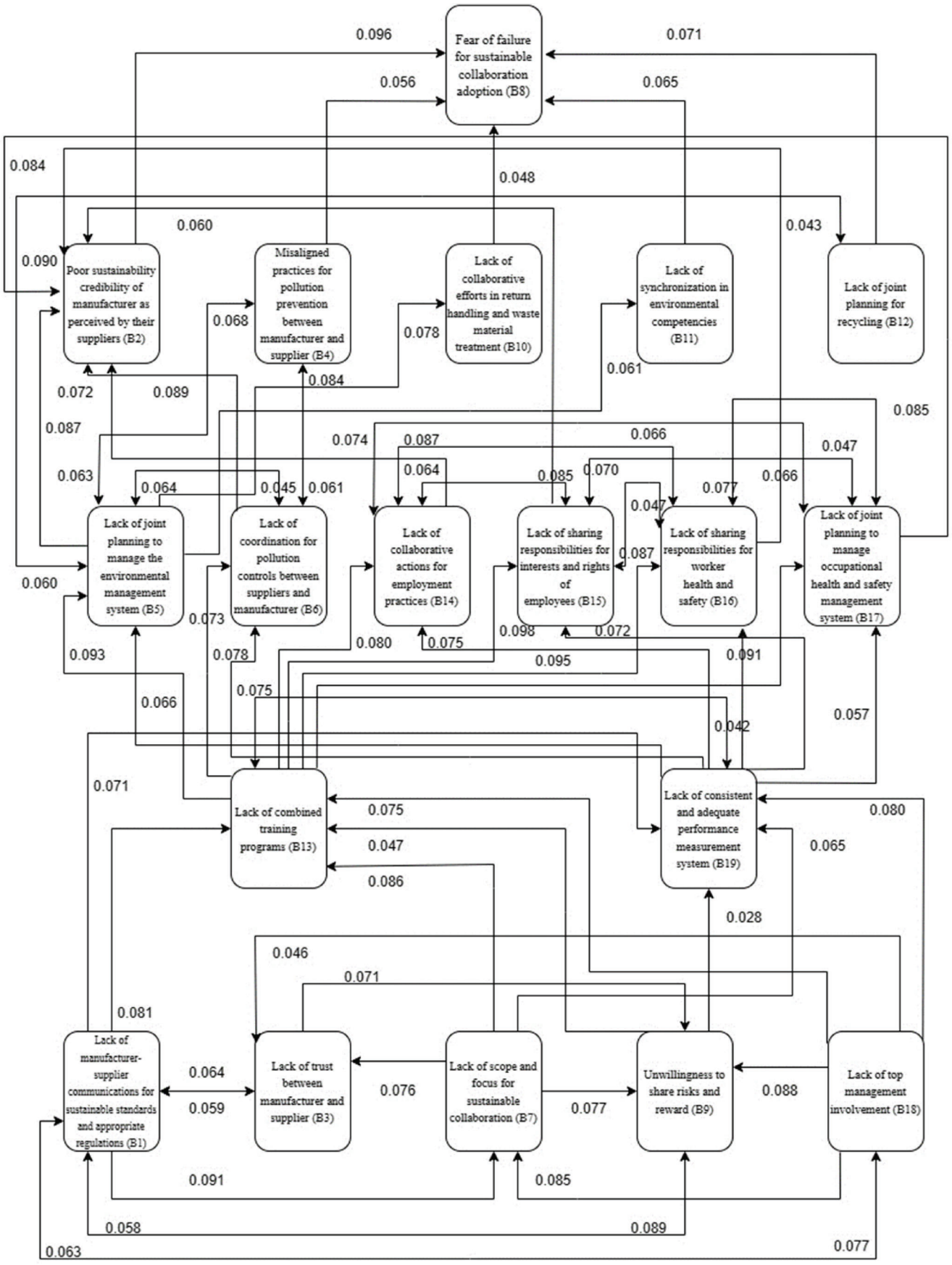

Fig. 6. Integrated TISM-DEMATEL based model.

the significant barriers are discussed in detail as follows:

Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}) is a foundational barrier in the implementation of sustainable manufacturer-supplier collaboration. Lack of communication between supplier and manufacturer hinders sustainable collaboration (Jääskeläinen and Thitz, 2018). To mitigate the lack of communication between a manufacturer and supplier in sustainable supplier-manufacturer collaboration adoption, it is important to establish open communication channels and define communication protocols. Fostering a collaborative culture and assigning communication focal points can further enhance communication effectiveness. Providing training and resources, leveraging collaborative tools and technologies, and conducting regular performance reviews contribute to improving communication. Encouraging feedback and continuous improvement ensures ongoing enhancements in communication processes. By implementing these strategies, manufacturers and suppliers can overcome communication challenges and lay the groundwork for successful sustainable collaboration.

Lack of trust between manufacturer and supplier (B_3^{SMSC}) is a big challenge for SMSC adoption. Non frequent, short-term interaction and opportunistic behavior between manufacturer and supplier create the trust issues between supplier and manufacturer (Butt et al., 2020). To mitigate the lack of trust between a manufacturer and supplier in the context of sustainable supplier-manufacturer collaboration adoption, one strategy is to establish a transparent and robust communication framework. This involves creating open channels for dialogue, actively sharing information, and promoting honest and frequent communication. By fostering an environment of transparency, both parties can address concerns, clarify misunderstandings, and build mutual understanding. Additionally, it is important to focus on building long-term relationships based on trust and mutual benefit. This can be achieved through consistent engagement, face-to-face meetings, and joint problem-solving initiatives. Investing time and effort in nurturing these relationships demonstrates a commitment to long-term collaboration and helps overcome initial trust barriers. Another strategy is to develop a shared vision and set of values that align with sustainability objectives. This common ground provides a sense of purpose and shared commitment, reinforcing trust between the manufacturer and supplier. Collaborative decision-making processes that involve input from both parties also contribute to building trust by ensuring that everyone's perspectives are considered and respected. Furthermore, implementing a robust performance monitoring and evaluation system can help build trust by demonstrating a commitment to agreed-upon sustainability goals and standards. By tracking progress, identifying areas for improvement, and holding each other accountable, trust is reinforced through a shared commitment to performance excellence. Lastly, emphasizing the mutual benefits of sustainable collaboration and showcasing the positive outcomes can help mitigate the lack of trust. By highlighting the advantages in terms of improved sustainability performance, cost savings, enhanced reputation, and market opportunities, both the manufacturer and supplier can see the value and beneficial incentives of working together.

In addition, lack of scope and focus for sustainable collaboration (B_7^{SMSC}) provides vague intentions instead of authentic motivations for collaboration (Knoppen and Sáenz, 2015). Several strategies can be utilized to address the issue of inadequate scope and focus in sustainable collaboration between manufacturers and suppliers. First, clear objectives should be defined, outlining specific sustainability goals, areas of focus, and expected outcomes. Collaborative goal-setting exercises should be conducted to ensure both parties have a shared vision and commitment. Sharing information and knowledge about sustainable practices and developing joint strategies help align efforts and utilize resources efficiently. Regular communication channels should be established to discuss progress, challenges, and opportunities, allowing for ongoing alignment and adjustments. Implementing a system for evaluation and improvement ensures the collaboration remains on track. Emphasizing the mutually beneficial aspects of sustainable collaboration helps maintain focus and encourages active participation. Long-term relationship building based on trust, shared values, and a commitment to sustainability strengthens the collaboration's foundation and sustained focus on sustainable initiatives. By implementing these strategies, manufacturers and suppliers can overcome any lack of scope and focus, leading to aligned efforts and meaningful progress towards shared sustainability goals.

Unwillingness to share risks and rewards (B_9^{SMSC}) creates barricades to collaboration by eroding trust, fostering imbalance, reducing motivation, limiting innovation, and constraining the collaboration's scope (Ali, 2021). Overcoming this barrier requires strategies such as emphasizing mutual benefits, building trust and open communication, developing fair agreements, aligning incentives, starting with pilot projects, fostering long-term partnerships, sharing knowledge and resources, and creating flexibility and adaptability can be employed. These strategies aim to promote a cooperative mindset, facilitate understanding and negotiations, motivate active participation, demonstrate the benefits of collaboration, cultivate strong partnerships, recognize the value each party brings, and provide mechanisms for ongoing collaboration and responsiveness. Implementing these strategies helps foster a more collaborative and mutually beneficial sustainable supplier-manufacturer collaboration.

Lack of top management involvement (B_{18}^{SMSC}) is one of the crucial barriers in the SMSC adoption. To mitigate the lack of top management involvement, strategies include securing senior leadership commitment, clearly communicating the business case, incorporating sustainability into performance metrics, providing training and education, engaging top management in goal-setting, implementing regular progress reporting, fostering cross-functional collaboration, and recognizing and rewarding sustainable collaboration efforts (Sikombe and Phiri, 2019). By implementing these strategies, manufacturers can foster a culture of sustainable collaboration from top management, align sustainability goals with strategic decision-making, and provide the necessary support and resources for successful collaboration.

Lack of combined training programs (B_{13}^{SMSC}) barrier arises when manufacturers and suppliers do not engage in collaborative training programs that address sustainability practices and requirements. The absence of combined training programs can hinder the development of shared knowledge, skills, and understanding necessary for effective collaboration on sustainability initiatives. It can result in misalignment of practices, inconsistent implementation of sustainable measures, and limited capacity to address sustainability challenges collectively. To overcome B_{13}^{SMSC}, manufacturers and suppliers can engage in collaborative training development, establish knowledge sharing platforms, organize cross-company training sessions, arrange onsite visits for experiential learning, utilize webinars and online resources, foster a culture of continuous learning, implement supplier development programs, and conduct regular evaluations and feedback (Moradlou et al., 2022). By implementing these strategies, manufacturers and suppliers can overcome the barrier, promote shared knowledge and skills, and enhance their ability to collaborate effectively on sustainability initiatives, driving positive change in their supply chains.

The (B_{19}^{SMSC}) barrier, lack of consistent and adequate performance measurement system, means it becomes challenging to assess and track the progress and impact of sustainability initiatives, which makes it difficult to identify areas for improvement and drive continuous advancement (Maestrini et al., 2018). Inconsistency in performance measurement across different manufacturing and supplier sites can result in a lack of comparability and hinder effective collaboration efforts. Additionally, the absence of clear performance metrics and targets can lead to ambiguity and a lack of accountability, making it harder to align goals and evaluate the success of collaborative sustainability initiatives. Overall, the absence of a consistent and adequate performance

measurement system limits the ability to measure, monitor, and optimize the sustainability performance of the collaborative efforts between manufacturers and suppliers. To mitigate B_{19}^{SMSC} in SMSC, strategies such as defining clear performance metrics, standardizing measurement practices, fostering collaborative monitoring, leveraging technology, providing capacity building and training, promoting continuous improvement and learning, conducting collaborative performance reviews, and offering supplier development and support can be employed. These strategies enable accurate evaluation, comparability, transparency, accountability, automation, enhanced understanding, benchmarking, and collaborative decision-making, ultimately facilitating effective monitoring, evaluation, and improvement of sustainability performance in collaborative efforts between manufacturers and suppliers.

Through the implementation of these strategies, manufacturers and suppliers can overcome barriers to sustainable collaboration and create a foundation for successful and impactful collaboration that drives sustainability across the supply chain.

6.2. MICMAC results

The driving power and dependence power of identified SMSC barriers are computed using MICMAC analysis. From the analysis, 19 SMSC barriers are categorized into four clusters (Fig. 6) as follows:

Cluster I: The first quadrant (first cluster) contains autonomous SMSC barriers. These SMSC barriers have weak dependence power and weak driving power. These barriers are not linked to any other SMSC barriers and thus exert no influence on the system. No SMSC is positioned in this quadrant. This infers that all the identified SMSC barriers are significant.

Cluster II: The second cluster of SMSC barriers, dependent barriers, have strong dependence power and weak driving power. Eleven SMSC barriers are present in this cluster. These are misaligned practices for pollution prevention between manufacturer and supplier (B_4^{SMSC}), lack of joint planning to manage the environmental management system (B_5^{SMSC}), lack of coordination for pollution controls between suppliers and manufacturer (B_6^{SMSC}), fear of failure for sustainable collaboration adoption (B_8^{SMSC}), lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}), lack of synchronization in environmental competencies (B_{11}^{SMSC}), lack of joint planning for recycling (B_{12}^{SMSC}), lack of collaborative actions for employment practices (B_{14}^{SMSC}), lack of sharing responsibilities for interests and rights of employees (B_{15}^{SMSC}), lack of sharing responsibilities for worker health and safety (B_{16}^{SMSC}), lack of joint planning to manage occupational health and safety management system (B_{17}^{SMSC}). Fear of failure for sustainable collaboration adoption (B_8^{SMSC}) exhibits the highest dependence power and it is dependent on all other SMSC barriers. Misaligned practices for pollution prevention between manufacturer and supplier, (B_4^{SMSC}), also has high dependence power; hence, other SMSC barriers can influence B_4^{SMSC}.

Cluster III: The third quadrant is comprised of linkage SMSC barriers. This cluster has SMSC barriers with strong dependence and strong driving power. Poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}), lack of scope and focus for sustainable collaboration (B_7^{SMSC}), unwillingness to share risks and rewards (B_9^{SMSC}) are the three factors presented in this cluster.

Cluster IV: Five SMSC barriers lie in the fourth quadrant cluster and have a weak dependence power but a strong driving power. These barriers are called driving SMSC barriers. Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}), lack of trust between manufacturer and supplier (B_3^{SMSC}), lack of combined training programs (B_{13}^{SMSC}), lack of top management involvement (B_{18}^{SMSC}), lack of consistent and adequate performance measurement system (B_{19}^{SMSC}) are the driving barriers. These barriers are key drivers and can influence all other SMSC barriers.

6.3. DEMATEL results

From TISM and MICMAC analysis, the interrelationship among SMSC barriers is determined but the intensity of that relationship is still unknown. Table 6 represents the intensity of relationships among the SMSC barriers. Some of the relationships are significant and some are not, so a threshold $\alpha = 0.010$ is set by the decision-making team. The values that are greater or equal than α are considered as significant relationships and marked in red.

Later, the values of prominence (r + c) and relation (r – c) are computed from total relation matrix as shown in Table 7. Based on (r - c) value, SMSC barriers are categorized into cause-and-effect groups. And with the help of (r + c) value, the SMSC barriers' ranking is determined. Both groups and their correlation among SMSC barriers are discussed as follows.

Cause Group: There are 7 SMSC barriers are in the cause group of SMSC barriers. These are lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}), lack of trust between manufacturer and supplier (B_3^{SMSC}), lack of scope and focus for sustainable collaboration (B_7^{SMSC}), unwillingness to share risks and rewards (B_9^{SMSC}), lack of combined training programs (B_{13}^{SMSC}), lack of top management involvement (B_{18}^{SMSC}), and lack of consistent and adequate performance measurement system (B_{19}^{SMSC}). Based on (r-c) value, the causal barriers are arranged as follows: lack of top management involvement (B_{18}^{SMSC}) > lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}) > lack of scope and focus for sustainable collaboration (B_7^{SMSC}) > lack of combined training programs (B_{13}^{SMSC}) > lack of consistent and adequate performance measurement system (B_{19}^{SMSC}) > lack of trust between manufacturer and supplier (B_3^{SMSC}) > unwillingness to share risks and rewards (B_9^{SMSC}). Lack of top management involvement (B_{18}^{SMSC}) is the primary cause barrier as per its top position in cause group. These results are discussed with industrial managers. During the discussion, they also considered B_{18}^{SMSC} as major barrier in the implementation of SMSC. Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}) is the second causal barrier to SMSC in the home appliances company. According to experts, the main blockade for SMSC implementation is unwillingness for communication between supply chain actors. Lack of scope and focus for sustainable collaboration (B_7^{SMSC}), lack of combined training programs (B_{13}^{SMSC}), lack of consistent and adequate performance measurement system (B_{19}^{SMSC}), lack of trust between manufacturer and supplier (B_3^{SMSC}), and unwillingness to share risks and rewards (B_9^{SMSC}) are also found to be the main barriers to SMSC implementation and have significant influence on other barriers.

Effect group: Barriers of the effect group are sorted as follows as per (r-c) value. First, lack of coordination for pollution controls between suppliers and manufacturer (B_6^{SMSC}) > lack of joint planning to manage the environmental management system (B_5^{SMSC}) > lack of joint planning to manage occupational health and safety management system (B_{17}^{SMSC}) > lack of joint planning for recycling (B_{12}^{SMSC}) > lack of sharing responsibilities for worker health and safety (B_{16}^{SMSC}) > lack of collaborative actions for employment practices (B_{14}^{SMSC}) > lack of synchronization in environmental competencies (B_{11}^{SMSC}) > lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}) > lack of sharing responsibilities for interests and rights of employees (B_{15}^{SMSC}) > misaligned practices for pollution prevention between manufacturer and supplier (B_4^{SMSC}) > poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}) > fear of failure for sustainable collaboration adoption (B_8^{SMSC}). These twelve barriers are highly

influenced by causal barriers that restricts the implementation of SMSC in home appliances company. Hence, these barriers can be removed by working on cause group barriers. Among all these, lack of coordination for pollution controls between suppliers and manufacturer (B_6^{SMSC}) is close to cause group that indicates B_6^{SMSC} has the least influence. In India, manufacturing companies are motivated to work with their supply chain partners on sustainability, but they still lack in coordinating their practices. If companies develop coordinated systems with their supply chain partners so necessary amenities for sustainable practices occur, sustainability performance will improve and SMSC will be more easily implemented. The next effect barriers in priority order are lack of joint planning to manage the environmental management system (B_5^{SMSC}) with (r-c) value of −0.263, followed by lack of joint planning to manage occupational health and safety management system (B_{17}^{SMSC}) with (r-c) value of −0.268, lack of joint planning for recycling (B_{12}^{SMSC}) with (r-c) value of −0.286, lack of sharing responsibilities for worker health and safety (B_{16}^{SMSC}) with (r-c) value of −0.302, lack of collaborative actions for employment practices (B_{14}^{SMSC}) with (r-c) value of −0.358, lack of synchronization in environmental competencies (B_{11}^{SMSC}) with (r-c) value of −0.416, lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}) with (r-c) value of −0.503, lack of sharing responsibilities for interests and rights of employees (B_{15}^{SMSC}) with (r-c) value of −0.511, misaligned practices for pollution prevention between manufacturer and supplier (B_4^{SMSC}) with (r-c) value of −0.561, poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}) with (r-c) value of −0.864, and fear of failure for sustainable collaboration adoption (B_8^{SMSC}) with (r-c) value of −1.689. It shows that B_8^{SMSC} is the least influencing SMSC barrier among all identified SMSC barriers to SMSC implementation.

The correlation among the SMSC Barriers: The importance of highly associated SMSC barriers with other barriers can be highlighted. With respect to prominence values (r + c), the measure of association of each SMSC barrier on the entire system is determined. The maximum value of (r + c) shows the highest overall prominence of SMSC barrier regarding importance compared to all other SMSC barriers. The relative importance order of SMSC barriers is as follows: Poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}) > lack of scope and focus for sustainable collaboration (B_7^{SMSC}) > unwillingness to share risks and rewards (B_9^{SMSC}) > lack of manufacturer-supplier communications for sustainable standards and appropriate regulations (B_1^{SMSC}) > lack of top management involvement (B_{18}^{SMSC}) > lack of combined training programs (B_{13}^{SMSC}) > fear of failure for sustainable collaboration adoption (B_8^{SMSC}) > lack of sharing responsibilities for worker health and safety(B_{16}^{SMSC}) > misaligned practices for pollution prevention between manufacturer and supplier (B_4^{SMSC}) > lack of consistent and adequate performance measurement system (B_{19}^{SMSC}) > lack of collaborative actions for employment practices (B_{14}^{SMSC}) > lack of joint planning to manage the environmental management system (B_5^{SMSC}) > lack of joint planning to manage occupational health and safety management system (B_{17}^{SMSC}) > lack of sharing responsibilities for interests and rights of employees (B_{15}^{SMSC}) > lack of coordination for pollution controls between suppliers and manufacturer (B_6^{SMSC}) > lack of trust between manufacturer and supplier (B_3^{SMSC}) > lack of joint planning for recycling (B_{12}^{SMSC}) > lack of synchronization in environmental competencies (B_{11}^{SMSC}) > lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}). Thus, poor sustainability credibility of manufacturer as perceived by their suppliers (B_2^{SMSC}) represents the highest correlation with other SMSC barriers; suppliers perceive the poor sustainability credibility of manufacturer as the biggest challenge in SMSC adoption. Implementation of SMSC requires sustainability credibility between manufacturer and supplier. The manufacturer's practices, such as frequent supplier switching, 'loss of business' trick for bargaining, inflexible specifications, misuse of power by quality authorities, or price-oriented buying, increase the credibility gap. Therefore, sustainability credibility is prerequisite to adopt SMSC. Once sustainability credibility is formed between manufacturer and supplier, manufacturing companies can reduce the impact of other SMSC barriers that may hinder the path of SMSC implementation. On the other hand, lack of collaborative efforts in return handling and waste material treatment (B_{10}^{SMSC}) has the least correlation with other SMSC barriers. Similarly, correlations among other SMSC barriers can be interpreted.

7. Managerial implications

In the current study, the novel framework of SMSC barriers in sustainable manufacturer-supplier collaboration that we have established offers substantial managerial implications. These implications can guide decision-making and strategic planning processes to overcome the identified SMSC barriers and to foster effective collaboration. Here are some managerial implications based on this study.

a) *Enhanced Understanding of SMSC Barriers:* The proposed framework provides a systematic and comprehensive approach to identify and analyze barriers in sustainable manufacturer-supplier collaboration. Managers can gain a deeper understanding of the specific challenges and obstacles that can hinder collaboration efforts. This understanding allows managers to develop targeted strategies and solutions to more effectively address these barriers.
b) *Improved Decision-Making:* By using the proposed framework, managers can make more informed and data-driven decisions regarding collaboration implementation. They can gain insights into the interrelationships among different barriers and can prioritize their efforts based on the severity and impact of each barrier. This improves the decision-making process and increases the likelihood of successful collaboration implementation.
c) *Targeted Resource Allocation:* The framework can assist managers in allocating resources efficiently and effectively. It enables them to identify the areas where resources are most needed to address specific barriers. By focusing resources on the critical barriers, managers can optimize resource allocation, minimize wastage, and maximize the impact of their investments in collaboration implementation.
d) *Risk Mitigation*: By understanding the potential barriers and challenges, managers can develop risk management strategies and contingency plans to minimize disruptions and ensure smooth implementation. This proactive approach reduces the likelihood of costly delays, conflicts, and failures in sustainable collaboration initiatives.
e) *Continuous Learning and Improvement:* By regularly assessing the SMSC barriers and their interrelationships, managers can identify opportunities for learning, innovation, and adaptation. This fosters a dynamic and agile approach to collaboration implementation, allowing managers to stay ahead of emerging challenges and to capitalize on new opportunities.
f) *Competitive Advantage:* By effectively addressing the barriers identified in the framework, managers can gain a competitive edge in the market. Sustainable collaboration initiatives lead to improved supply chain performance, enhanced brand reputation, reduced costs, and increased customer loyalty. This positions the organization as a leader in sustainability, attracting environmentally conscious customers and stakeholders and differentiating the organization from its competitors.

Overall, the novel framework of barriers in SMSC provides managers with a structured approach to identify, analyze, and overcome barriers in collaboration implementation. By leveraging this framework, managers can drive successful and impactful sustainable collaboration initiatives that benefit their organization, suppliers, and the wider society.

8. Conclusion

SMSC requires that traditional supplier management system is extended with long term relationships under sustainable aspects by manufacturing companies. SMSC barriers have become an important aspect in the implementation of SMSC. Consequently, manufacturing companies must develop a systematic model for clear understanding of challenges while implementing SMSC. Traditional supplier management systems should recognize the value of long term relationships under sustainable aspects. There have been several publications that related to SMSC or barrier analysis, but none has considered barrier analysis for SMSC. In this work, an exhaustive list of barriers for an Indian home appliances company to implement sustainable collaboration between supplier and manufacturer is identified with the help of experts and literature review. Then, an integrated TISM-DEMATEL approach is applied to develop a structural model as per the identified SMSC barriers and inputs from decision makers. Then, the most dominant SMSC barriers are prioritized to aid practitioners and industrial decision-makers.

This study offers two key contributions. First, the identification of a full set of SMSC barriers is done by reviewing the literature and experts' opinion. Furthermore, each SMSC barrier is explained in detail that can provide useful learning insights into understanding of SMSC barriers for effective implementation of SMSC.

The current work contains a few limitations that can serve as a platform for future theoretical and empirical research in this domain. First, in this study, 19 SMSC barriers are identified. Other SMSC barriers have not been identified that may be crucial in an effective SMSC implementation. Second, the structural model is constructed on the basis of TISM-DEMATEL methodology. The methodology has its own limitations such as high dependency on judgment of the experts. The effect of human biasness has not been considered in the study while analyzing SMSC barriers. These limitations could be extended in future work. The proposed solution methodology could be extended to other industries for achieving SSC. For improving the accuracy and reliability of the model, the current work may be validated through other MCDM techniques. Further, sensitivity analysis can be executed to observe the influence of the choices of experts for SMSC barrier analysis.

CRediT authorship contribution statement

Aditi: Conceptualization, Methodology, Writing – original draft, preparation, Investigation. **Kannan Govindan:** Conceptualization, Methodology, Writing – original draft, preparation, Investigation, Supervision. **P.C. Jha:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no potential conflict of interest was reported by the authors in this paper.

Data availability

Included in the paper

Appendix A

Table A.1
Barrier notation, contextual relationship, and interpretation for sustainable manufacturer supplier collaboration.

Barrier Notation	Contextual relation	Interpretation
B_1^{SMSC}	SMSC barrier A will influence SMSC barrier B	How or in what way will SMSC barrier A influence SMSC barrier B?
B_2^{SMSC}		
B_3^{SMSC}		
B_4^{SMSC}		
B_5^{SMSC}		
B_6^{SMSC}		
B_7^{SMSC}		
B_8^{SMSC}		
B_9^{SMSC}		
B_{10}^{SMSC}		
B_{11}^{SMSC}		
B_{12}^{SMSC}		
B_{13}^{SMSC}		
B_{14}^{SMSC}		
B_{15}^{SMSC}		
B_{16}^{SMSC}		
B_{17}^{SMSC}		
B_{18}^{SMSC}		
B_{19}^{SMSC}		

Table A.2
Initial reachability matrix of the barriers.

	B_1^{SMSC}	B_2^{SMSC}	B_3^{SMSC}	B_4^{SMSC}	B_5^{SMSC}	B_6^{SMSC}	B_7^{SMSC}	B_8^{SMSC}	B_9^{SMSC}	B_{10}^{SMSC}	B_{11}^{SMSC}	B_{12}^{SMSC}	B_{13}^{SMSC}	B_{14}^{SMSC}	B_{15}^{SMSC}	B_{16}^{SMSC}	B_{17}^{SMSC}	B_{18}^{SMSC}	B_{19}^{SMSC}
B_1^{SMSC}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B_2^{SMSC}	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
B_3^{SMSC}	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
B_4^{SMSC}	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
B_5^{SMSC}	0	1	0	1	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0
B_6^{SMSC}	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
B_7^{SMSC}	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
B_8^{SMSC}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
B_9^{SMSC}	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0
B_{10}^{SMSC}	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
B_{11}^{SMSC}	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
B_{12}^{SMSC}	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0
B_{13}^{SMSC}	0	1	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1
B_{14}^{SMSC}	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0
B_{15}^{SMSC}	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0
B_{16}^{SMSC}	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0
B_{17}^{SMSC}	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0
B_{18}^{SMSC}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B_{19}^{SMSC}	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1

Table A.3
Interpretation of contextual relationship between barriers for sustainable manufacturer supplier collaboration.

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
1	B_1^{SMSC}-B_2^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	Lack of communication on sustainable standards and regulations between manufacturers and suppliers diminishes the manufacturer's sustainability credibility as perceived by suppliers due to inconsistent practices, compliance issues, missed opportunities, limited collaboration, and erosion of trust.
2	B_1^{SMSC}-B_3^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of trust between manufacturer and supplier.	The lack of manufacturer-supplier communication for sustainable standards and appropriate regulations undermines trust between the two parties due to a lack of transparency, inability to align on sustainability goals, potential compliance issues, missed collaboration opportunities, and perceptions of disregard for ethical and environmental concerns.
3	B_1^{SMSC}-B_4^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts misaligned practices for pollution prevention between manufacturer and supplier.	Without effective communication, manufacturers and suppliers may have different understandings and approaches to pollution prevention, resulting in inconsistent practices, increased environmental impact, and a lack of synergy in their sustainability efforts.
4	B_1^{SMSC}-B_5^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of joint planning to manage the environmental management system.	Without effective communication, manufacturers and suppliers fail to align their efforts, leading to fragmented approaches, missed opportunities for collaboration, and suboptimal environmental management practices.
5	B_1^{SMSC}-B_6^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of coordination for pollution controls between suppliers and manufacturer.	Lack of manufacturer-supplier communication for sustainable standards and regulations results in a lack of coordination for pollution controls, leading to inconsistent implementation and monitoring of pollution control measures, ultimately compromising the effectiveness of pollution control efforts between suppliers and manufacturer.
6	B_1^{SMSC}-B_7^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of scope and focus for sustainable collaboration.	The lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts the lack of scope and focus for sustainable collaboration by inhibiting the sharing of goals, strategies, and expectations.
7	B_1^{SMSC}-B_8^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts fear of failure for sustainable collaboration adoption.	Without effective communication, there is a lack of clarity and understanding of expectations, resulting in uncertainty about meeting sustainability goals and potential negative consequences, leading to hesitancy and fear of failure in the collaborative adoption of sustainable practices.
8	B_1^{SMSC}-B_9^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts unwillingness to share risks and rewards.	Insufficient communication undermines trust and understanding between manufacturers and suppliers, resulting in hesitancy to share the risks and rewards of sustainable collaboration. This communication gap hampers the formation of mutually beneficial partnerships and limits the adoption of shared responsibility for achieving sustainability goals.
9	B_1^{SMSC}-B_{10}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of collaborative efforts in return handling and waste material treatment.	Insufficient communication results in a lack of coordination and alignment between manufacturers and suppliers in managing returns and treating waste materials sustainably. This impedes the establishment of efficient and eco-friendly practices, ultimately leading to suboptimal return handling and waste management processes.
10	B_1^{SMSC}-B_{11}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of synchronization in environmental competencies.	Without effective communication, manufacturers and suppliers may have differing levels of understanding and implementation of environmental practices and standards. This lack of synchronization hampers the development of shared environmental competencies and impedes the establishment of consistent and aligned sustainability efforts across the supply chain.
11	B_1^{SMSC}-B_{12}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of joint planning for recycling.	Due to lack of communication, there is a failure to coordinate efforts, share information, and align strategies, resulting in a fragmented approach to recycling and a missed opportunity for collaborative and efficient recycling practices.
12	B_1^{SMSC}-B_{13}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of combined training programs.	Without effective communication, manufacturers and suppliers miss the opportunity to collaborate on training initiatives aimed at promoting sustainable practices. This results in a lack of shared knowledge and skills, hindering the development of combined training programs that could enhance sustainability efforts across the supply chain.
13	B_1^{SMSC}-B_{14}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of collaborative actions for employment practices.	Insufficient communication between manufacturers and suppliers prevents the alignment of efforts to promote sustainable employment practices, leading to a lack of coordination and shared initiatives. This limitation undermines the potential impact of collaborative actions on areas like fair labor standards, diversity and inclusion, and employee well-being programs.
14	B_1^{SMSC}-B_{15}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of sharing responsibilities for interests and rights of employees.	Insufficient communication between manufacturers and suppliers hinders the establishment of clear expectations and commitments for employee welfare and rights. This limitation impedes collaborative efforts to ensure the well-being, fair treatment, and protection of employee interests and rights throughout the supply chain.
15	B_1^{SMSC}-B_{16}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of sharing responsibilities for worker health and safety.	Without effective communication, manufacturers and suppliers may not establish clear expectations and commitments regarding the health and safety of workers. This lack of sharing responsibilities hampers the development of

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Table A.3 (*continued*)

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
			collaborative efforts to ensure a safe working environment and effective safety practices throughout the supply chain.
16	B_1^{SMSC}-B_{17}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of joint planning to manage occupational health and safety management system.	The absence of effective communication hinders the coordination, alignment, and information sharing between manufacturers and suppliers in developing strategies for occupational health and safety. This lack of joint planning undermines the establishment of a cohesive and thorough approach to managing occupational health and safety, thereby compromising the effectiveness of the management system.
17	B_1^{SMSC}-B_{18}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of top management involvement.	Without effective communication, manufacturers and suppliers may not engage top-level management in discussions and decision-making processes related to sustainability. This lack of involvement hampers the development of a shared vision, commitment, and accountability at the highest level of the organization, hindering the implementation and integration of sustainable practices throughout the supply chain.
18	B_1^{SMSC}-B_{19}^{SMSC}	Lack of manufacturer-supplier communications for sustainable standards and appropriate regulations impacts lack of consistent and adequate performance measurement system.	In the absence of effective communication, manufacturers and suppliers may not have shared understanding and alignment on the criteria, metrics, and methodologies for measuring sustainability performance. This lack of coordination and agreement hampers the development of a standardized and robust performance measurement system, making it challenging to accurately assess and compare sustainability outcomes across the supply chain.
19	B_2^{SMSC}-B_4^{SMSC}	Poor sustainability credibility of manufacturer as perceived by their suppliers impacts misaligned practices for pollution prevention between manufacturer and supplier.	Suppliers, perceiving the manufacturer's low credibility in sustainability, may not prioritize or align their efforts with the manufacturer's pollution prevention practices. This misalignment can result in inconsistent or inadequate pollution prevention measures, hindering the overall effectiveness of sustainability initiatives within the supply chain.
20	B_2^{SMSC}-B_7^{SMSC}	Poor sustainability credibility of manufacturer as perceived by their suppliers impacts lack of scope and focus for sustainable collaboration.	Suppliers may be reluctant to engage in collaborative efforts with a manufacturer they perceive as lacking credibility in sustainability practices. This lack of trust and confidence hampers the development of focused and comprehensive sustainable collaboration initiatives, limiting the scope and effectiveness of joint efforts to achieve sustainability goals.
21	B_2^{SMSC}-B_8^{SMSC}	Poor sustainability credibility of manufacturer as perceived by their suppliers impacts fear of failure for sustainable collaboration adoption.	Suppliers may hesitate to engage in collaborative efforts with a manufacturer they perceive as lacking credibility in sustainability practices, fearing that their own reputation and efforts may be compromised. This fear of failure inhibits the willingness to adopt sustainable collaboration initiatives, hindering the progress towards shared sustainability goals and impeding the potential benefits of collaboration in driving positive environmental and social outcomes.
22	B_2^{SMSC}-B_9^{SMSC}	Poor sustainability credibility of manufacturer as perceived by their suppliers impacts unwillingness to share risks and rewards.	Suppliers, perceiving the manufacturer as lacking credibility in sustainability practices, may be hesitant to collaborate on shared initiatives and bear the associated risks. This lack of trust and confidence hinders the willingness to engage in risk-sharing arrangements, leading to a reluctance to jointly pursue sustainable goals and share the potential rewards of successful collaboration.
23	B_3^{SMSC}-B_1^{SMSC}	Lack of trust between manufacturer and supplier impacts lack of manufacturer-supplier communications for sustainable standards and appropriate regulations.	In the absence of trust, there is a reluctance from both the manufacturer and the supplier to openly communicate and exchange information regarding sustainability practices. This lack of communication impedes the establishment of effective channels for discussing and aligning on sustainable standards and regulations, thereby hindering the progress of collaborative efforts in meeting and complying with these standards.
24	B_3^{SMSC}-B_2^{SMSC}	Lack of trust between manufacturer and supplier impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	In the absence of trust, suppliers may question the authenticity of the manufacturer's sustainability claims and initiatives, casting doubt on their genuine dedication to sustainability. This perception of inadequate sustainability credibility diminishes the trust suppliers have in the manufacturer's sustainability practices, potentially impacting their readiness to participate in collaborative endeavors or establish enduring partnerships.
25	B_3^{SMSC}-B_8^{SMSC}	Lack of trust between manufacturer and supplier impacts fear of failure for sustainable collaboration adoption.	When trust is lacking, both parties may be apprehensive about the potential risks and uncertainties associated with collaborative efforts. This fear of failure arises from concerns about the reliability and commitment of the other party, hindering the willingness to embrace sustainable collaboration and explore innovative approaches.
26	B_3^{SMSC}-B_9^{SMSC}	Lack of trust between manufacturer and supplier impacts unwillingness to share risks and rewards.	Lack of trust between a manufacturer and a supplier leads to reluctance in sharing risks and rewards, as both parties are hesitant to engage in collaborative efforts due to concerns about trustworthiness and reliability. This unwillingness to share risks and rewards hinders the development of mutually beneficial partnerships and limits the potential for collective success in pursuing sustainability goals.
27	B_4^{SMSC}-B_2^{SMSC}	Misaligned practices for pollution prevention between manufacturer and supplier impact poor sustainability credibility of manufacturer as perceived by their suppliers.	Misaligned practices for pollution prevention between a manufacturer and a supplier erode the sustainability credibility of the manufacturer in the eyes of their suppliers, as it signals a lack of commitment and effectiveness in addressing environmental concerns. This perception negatively impacts trust, supplier relationships, and the overall reputation of the manufacturer in terms of sustainability.

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S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
28	B_4^{SMSC}-B_5^{SMSC}	Misaligned practices for pollution prevention between manufacturer and supplier impact lack of joint planning to manage the environmental management system.	Misaligned practices for pollution prevention between a manufacturer and a supplier hinder joint planning for managing the environmental management system, as they create a lack of synchronization and coordination in efforts and strategies. This lack of joint planning undermines the establishment of an integrated and effective approach to environmental management, limiting the ability to achieve shared sustainability goals and optimize environmental performance.
29	B_4^{SMSC}-B_6^{SMSC}	Misaligned practices for pollution prevention between manufacturer and supplier impact lack of coordination for pollution controls between suppliers and manufacturer.	Without aligned practices, it becomes challenging to establish consistent standards, share information, and coordinate efforts to effectively control and mitigate pollution. This lack of coordination hampers the overall effectiveness of pollution control measures and compromises the environmental performance of both the supplier and the manufacturer.
30	B_4^{SMSC}-B_8^{SMSC}	Misaligned practices for pollution prevention between manufacturer and supplier impact fear of failure for sustainable collaboration adoption (mutual lack of confidence).	The lack of alignment in pollution prevention practices raises concerns about the compatibility of their approaches and the potential for negative outcomes. This fear of failure inhibits the willingness to engage in sustainable collaboration efforts, as there is uncertainty about the success and effectiveness of such initiatives, which hinders progress towards shared sustainability goals.
31	B_5^{SMSC}-B_2^{SMSC}	Lack of joint planning to manage the environmental management system impacts poor sustainability credibility of manufacturer as perceived by their suppliers; there is an unclear vision for sustainable goals.	Without effective coordination and planning, the manufacturer may struggle to implement robust environmental practices and systems. This lack of coordination and inadequate management of environmental aspects can erode the suppliers' trust in the manufacturer's commitment to sustainability, leading to a perception of poor sustainability credibility.
32	B_5^{SMSC}-B_4^{SMSC}	Lack of joint planning to manage the environmental management system impacts misaligned practices for pollution prevention between manufacturer and supplier (lack of cooperation).	The absence of a synchronized approach to environmental management may lead to the independent development of strategies and initiatives by both the manufacturer and supplier, resulting in inconsistent and divergent pollution prevention practices. This lack of coordinated planning hinders effective collaboration and coordination between the two parties, making it difficult to align their efforts in addressing environmental concerns and achieving mutually agreed upon goals for sustainable pollution prevention.
33	B_5^{SMSC}-B_6^{SMSC}	Lack of joint planning to manage the environmental management system impacts lack of coordination for pollution controls between suppliers and manufacturer.	Without a coordinated approach, there may be inconsistencies and gaps in implementing pollution control measures, leading to a lack of harmonization in pollution control efforts. This lack of coordination compromises the effectiveness of pollution control measures and hampers the ability to achieve consistent and sustainable environmental outcomes.
34	B_5^{SMSC}-B_8^{SMSC}	Lack of joint planning to manage the environmental management system impacts fear of failure for sustainable collaboration adoption.	Without a clear plan and shared understanding of responsibilities, stakeholders may hesitate to fully commit to sustainable collaboration initiatives due to concerns about potential risks and the possibility of not achieving desired outcomes. This lack of joint planning undermines trust and confidence, making it challenging to drive meaningful and successful sustainable collaboration efforts.
35	B_5^{SMSC}-B_{10}^{SMSC}	Lack of joint planning to manage the environmental management system impacts lack of collaborative efforts in return handling and waste material treatment.	Without a shared plan and clear guidelines, there is a risk of inconsistent practices and inefficient processes in managing returns and waste materials. This lack of collaborative efforts hampers the development of effective and sustainable strategies for return handling and waste material treatment, potentially leading to suboptimal environmental outcomes and increased resource wastage.
36	B_5^{SMSC}-B_{11}^{SMSC}	Lack of joint planning to manage the environmental management system impacts lack of synchronization in environmental competencies.	The absence of a synchronized approach to developing and enhancing environmental competencies can lead to differences in knowledge, skills, and practices related to sustainability and environmental stewardship. This lack of coordination inhibits effective collaboration and the alignment of efforts towards shared sustainability goals, potentially leading to inefficient resource utilization, missed improvement opportunities, and subpar environmental performance.
37	B_5^{SMSC}-B_{12}^{SMSC}	Lack of joint planning to manage the environmental management system impacts lack of joint planning for recycling.	The absence of joint planning to manage the environmental management system creates a barrier to coordinating efforts and strategies for recycling. Without effective communication and coordination, manufacturers and suppliers struggle to align their recycling initiatives and establish a cohesive approach to managing recycling processes, leading to a lack of joint planning and suboptimal recycling practices.
38	B_6^{SMSC}-B_2^{SMSC}	Lack of coordination for pollution controls between suppliers and manufacturer impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	Lack of pollution control coordination between suppliers and manufacturers undermines the manufacturer's sustainability credibility, as suppliers perceive it as a lack of commitment to effective pollution control measures, eroding trust and hindering collaborative relationships.
39	B_6^{SMSC}-B_4^{SMSC}	Lack of coordination for pollution controls between suppliers and manufacturer impacts misaligned practices for pollution prevention between manufacturer and supplier.	The lack of coordination for pollution controls between suppliers and manufacturers leads to misaligned practices for pollution prevention, as each party may develop their own strategies, resulting in inconsistencies and discrepancies in pollution prevention measures.
40	B_6^{SMSC}-B_5^{SMSC}	Lack of coordination for pollution controls between suppliers and manufacturer impacts lack of joint planning to manage the environmental management system.	The lack of coordination for pollution controls between suppliers and manufacturers restricts the development of joint planning to manage the environmental management system, as there is a lack of collaboration and alignment in implementing and coordinating environmental initiatives and strategies.

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S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
41	B_6^{SMSC}-B_8^{SMSC}	Lack of coordination for pollution controls between suppliers and manufacturer impacts fear of failure for sustainable collaboration adoption.	The lack of coordination for pollution controls between suppliers and manufacturers can instill a fear of failure when considering the adoption of sustainable collaboration. This fear arises from concerns about the potential consequences of inadequate pollution control measures and the inability to achieve desired sustainability outcomes through joint efforts.
42	B_7^{SMSC}-B_2^{SMSC}	Lack of scope and focus for sustainable collaboration impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	The lack of scope and focus for sustainable collaboration can negatively impact the sustainability credibility of a manufacturer as perceived by their suppliers. Suppliers may view the limited scope and lack of clear focus as a sign of insufficient commitment to sustainability. This perception can erode trust and diminish the manufacturer's credibility in terms of their overall sustainability practices, hindering the development of strong, collaborative relationships centered around sustainability goals.
43	B_7^{SMSC}-B_3^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of trust between manufacturer and supplier.	When there is a lack of clear direction and limited scope for collaboration on sustainability initiatives, it can create uncertainty and doubt about the manufacturer's commitment to sustainable practices. This can erode trust between the parties, hindering effective communication, collaboration, and the development of mutually beneficial relationships.
44	B_7^{SMSC}-B_4^{SMSC}	Lack of scope and focus for sustainable collaboration impacts misaligned practices for pollution prevention between manufacturer and supplier.	Without a clear and shared understanding of sustainability goals and objectives, manufacturer and supplier may develop their own approaches and priorities for pollution prevention. This lack of alignment can lead to inconsistent practices, duplication of efforts, and potential gaps in pollution prevention measures. It hampers effective collaboration and coordination, hindering the ability to address pollution issues in a comprehensive and synchronized manner.
45	B_7^{SMSC}-B_5^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of joint planning to manage the environmental management system.	Without a clear vision and shared objectives for sustainability, both manufacturer and supplier may struggle to align their efforts and coordinate strategies for managing the environmental management system. This lack of joint planning hinders the establishment of an integrated and comprehensive approach to environmental management, potentially leading to inefficiencies, missed opportunities, and suboptimal environmental performance.
46	B_7^{SMSC}-B_6^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of coordination for pollution controls between suppliers and manufacturer.	The lack of scope and focus for sustainable collaboration between suppliers and manufacturers can lead to various challenges in coordinating pollution controls. It can result in misaligned goals, inconsistent standards, communication gaps, limited resource allocation, missed innovation opportunities, and compliance issues.
47	B_7^{SMSC}-B_8^{SMSC}	Lack of scope and focus for sustainable collaboration impacts fear of failure for sustainable collaboration adoption.	Lack of scope and focus in sustainable collaboration increases the fear of failure by creating uncertainty about objectives, accountability, and outcomes. It hinders effective implementation, limits learning opportunities, and leads to perceived wasted efforts, intensifying the fear of failure among participants.
48	B_7^{SMSC}-B_9^{SMSC}	Lack of scope and focus for sustainable collaboration impacts unwillingness to share risks and rewards.	Lack of scope and focus in sustainable collaboration creates uncertainty and ambiguity, leading to unwillingness to share risks and rewards. It hampers the establishment of fair distribution mechanisms and fosters risk aversion between manufacturer and supplier.
49	B_7^{SMSC}-B_{10}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of collaborative efforts in return handling and waste material treatment.	Lack of scope and focus in sustainable collaboration hampers collaborative efforts in return handling and waste material treatment by causing inefficiencies, disorganized practices, and limited information sharing. It leads to suboptimal management of returns and waste, missed recycling opportunities, and increased environmental impacts.
50	B_7^{SMSC}-B_{11}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of synchronization in environmental competencies.	Lack of scope and focus for sustainable collaboration hinders the synchronization of environmental competencies by creating inconsistency in knowledge and skills related to sustainability practices among participants. This lack of synchronization can impede effective collaboration and hinder the implementation of coordinated environmental initiatives.
51	B_7^{SMSC}-B_{12}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of joint planning for recycling.	Lack of scope and focus for sustainable collaboration impacts the lack of joint planning for recycling by hindering coordinated efforts, shared goals, and clear strategies for recycling initiatives. Without a unified approach, there can be inefficiencies, inconsistent practices, and missed opportunities in recycling planning and implementation.
52	B_7^{SMSC}-B_{13}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of combined training programs.	Lack of scope and focus for sustainable collaboration impacts the lack of combined training programs by preventing the development and implementation of unified training initiatives. Without a clear direction, coordination, and shared objectives, participants may receive inconsistent or insufficient training on sustainability practices, leading to a gap in combined knowledge and skills.
53	B_7^{SMSC}-B_{14}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of collaborative actions for employment practices.	Lack of scope and focus for sustainable collaboration impacts the lack of collaborative actions for employment practices by hindering the establishment of common goals and strategies. Without clear direction, participants may not coordinate efforts to implement sustainable employment practices, leading to inconsistent approaches and missed opportunities for collective impact.
54	B_7^{SMSC}-B_{15}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of sharing responsibilities for interests and rights of employees.	Without clear guidelines and a focused approach, there may be a reluctance or inability to effectively address and prioritize employee interests and rights, resulting in gaps in responsibility sharing and potential infringements on their well-being.

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S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
55	B_7^{SMSC}-B_{16}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of sharing responsibilities for worker health and safety.	Lack of scope and focus for sustainable collaboration leads to a lack of sharing responsibilities for worker health and safety. Without a clear framework, there is a lack of coordination and accountability, resulting in inadequate safety measures, increased risks for employees, and a failure to address worker health and safety concerns collectively.
56	B_7^{SMSC}-B_{17}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of joint planning to manage occupational health and safety management system.	Without a clear direction and coordinated efforts, there is a failure to establish unified plans and strategies for managing occupational health and safety. This can result in inconsistencies, gaps, and missed opportunities in effectively addressing and improving occupational health and safety practices.
57	B_7^{SMSC}-B_{19}^{SMSC}	Lack of scope and focus for sustainable collaboration impacts lack of consistent and adequate performance measurement system.	Without clear objectives and a focused approach, there may be no standardized metrics or guidelines for evaluating sustainability performance. This leads to inconsistencies in measuring progress, making it challenging to assess the effectiveness of sustainability initiatives and identify areas for improvement.
58	B_9^{SMSC}-B_1^{SMSC}	Unwillingness to share risks and rewards impacts lack of manufacturer-supplier communications for sustainable standards and appropriate regulations.	Unwillingness to share risks and rewards can hinder trust and information exchange, impeding collaborative efforts between manufacturers and suppliers to establish sustainable standards and appropriate regulations. This lack of communication can stifle innovation, lead to compliance challenges, and hinder progress towards sustainability goals.
59	B_9^{SMSC}-B_4^{SMSC}	Unwillingness to share risks and rewards impacts misaligned practices for pollution prevention between manufacturer and supplier.	Unwillingness to share risks and rewards acts as a barrier that hinders effective collaboration and coordination between manufacturers and suppliers, resulting in misaligned practices for pollution prevention. This can lead to inconsistencies, inefficiencies, and a failure to address pollution issues holistically throughout the supply chain.
60	B_9^{SMSC}-B_5^{SMSC}	Unwillingness to share risks and rewards impacts lack of joint planning to manage the environmental management system.	Unwillingness to share risks and rewards results in a lack of collaboration and coordination between stakeholders, leading to a fragmented and ineffective approach in jointly planning and managing the environmental management system, hindering the achievement of shared environmental goals.
61	B_9^{SMSC}-B_6^{SMSC}	Unwillingness to share risks and rewards impacts lack of coordination for pollution controls between suppliers and manufacturer.	The unwillingness to share risks and rewards undermines coordination for pollution controls between suppliers and manufacturers, potentially resulting in inconsistent implementation and gaps or duplication in pollution control efforts. This hinders the overall effectiveness of pollution management within the supply chain.
62	B_9^{SMSC}-B_8^{SMSC}	Unwillingness to share risks and rewards impacts fear of failure for sustainable collaboration adoption.	Unwillingness to share risks and rewards reinforces a fear of failure in adopting sustainable collaboration practices due to the risk-averse environment it creates and the lack of incentives for investment and innovation, hindering the willingness to embrace change and impeding the adoption of sustainable collaboration initiatives.
63	B_9^{SMSC}-B_{10}^{SMSC}	Unwillingness to share risks and rewards impacts lack of collaborative efforts in return handling and waste material treatment.	Unwillingness to share risks and rewards contributes to a lack of collaborative efforts in return handling and waste material treatment, as it discourages the joint planning, resource sharing, and coordination necessary for effective and sustainable management of returns and waste materials. This leads to inefficient and fragmented practices, missed opportunities for recycling or repurposing, and increased environmental impact.
64	B_9^{SMSC}-B_{11}^{SMSC}	Unwillingness to share risks and rewards impacts lack of synchronization in environmental competencies.	Unwillingness to share risks and rewards results in a lack of synchronization in environmental competencies between manufacturers and suppliers, as it hinders the exchange of knowledge, best practices, and resources needed to develop and align environmental competencies. This lack of synchronization can lead to inconsistencies, inefficiencies, and missed opportunities for improving environmental performance and sustainability.
65	B_9^{SMSC}-B_{12}^{SMSC}	Unwillingness to share risks and rewards impacts lack of joint planning for recycling.	Unwillingness to share risks and rewards hampers the development of joint planning for recycling initiatives, impeding the coordination and collaboration necessary to establish efficient recycling systems, optimize resource utilization, and address environmental challenges effectively. This lack of joint planning leads to fragmented recycling efforts, missed opportunities for synergies, and limited progress towards sustainable recycling practices.
66	B_9^{SMSC}-B_{13}^{SMSC}	Unwillingness to share risks and rewards impacts lack of combined training programs.	Unwillingness to share risks and rewards contributes to a lack of combined training programs between manufacturers and suppliers. This lack of collaboration and sharing of resources and knowledge hinders the development of comprehensive and coordinated training programs, limiting the effectiveness of training initiatives, and impeding the alignment of skills and competencies related to sustainable practices.
67	B_9^{SMSC}-B_{14}^{SMSC}	Unwillingness to share risks and rewards impacts lack of collaborative actions for employment practices.	Unwillingness to share risks and rewards impacts the lack of collaborative actions for employment practices between manufacturers and suppliers. This lack of collaboration hinders the development of joint initiatives and shared responsibilities, leading to inconsistent employment practices, missed opportunities for collective improvement, and potential labor-related challenges within the supply chain.

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S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
68	B_9^{SMSC}-B_{15}^{SMSC}	Unwillingness to share risks and rewards impacts lack of sharing responsibilities for interests and rights of employees.	The unwillingness to share risks and rewards negatively impacts the sharing of responsibilities for the interests and rights of employees. It undermines accountability, fosters a fragmented approach, creates communication gaps, and hinders progress in improving labor conditions and ensuring fair treatment throughout the supply chain.
69	B_9^{SMSC}-B_{16}^{SMSC}	Unwillingness to share risks and rewards impacts lack of sharing responsibilities for worker health and safety.	Unwillingness to share risks and rewards results in a lack of sharing responsibilities for work health and safety, leading to inadequate collaboration, fragmented efforts, and a failure to establish consistent and effective practices to ensure a safe and healthy work environment.
70	B_9^{SMSC}-B_{17}^{SMSC}	Unwillingness to share risks and rewards impacts lack of joint planning to manage occupational health and safety management system.	Unwillingness to share risks and rewards impacts the lack of joint planning to manage the occupational health and safety management system by hindering collaboration, coordination, and resource sharing between manufacturers and suppliers. This lack of joint planning leads to fragmented efforts, inconsistencies in safety practices, and a reduced ability to establish a comprehensive and effective occupational health and safety management system.
71	B_{10}^{SMSC}-B_2^{SMSC}	Lack of collaborative efforts in return handling and waste material treatment impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	The lack of collaborative efforts in return handling and waste material treatment undermines the sustainability credibility of manufacturers as perceived by their suppliers. It raises concerns about commitment, resource efficiency, circular economy practices, and compliance, ultimately impacting the trust and perception of manufacturers' sustainability credentials.
72	B_{10}^{SMSC}-B_8^{SMSC}	Lack of collaborative efforts in return handling and waste material treatment impacts fear of failure for sustainable collaboration adoption.	The lack of collaborative efforts in return handling and waste material treatment intensifies the fear of failure for adopting sustainable collaboration practices. Limited knowledge sharing, inefficient resource utilization, missed innovation opportunities, and increased risk aversion all contribute to this fear, making stakeholders hesitant to embrace and invest in sustainable collaboration initiatives.
73	B_{11}^{SMSC}-B_2^{SMSC}	Lack of synchronization in environmental competencies impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	The lack of synchronization in environmental competencies impacts the sustainability credibility of manufacturers as perceived by their suppliers. Inconsistent practices, missed collaboration opportunities, reduced supplier confidence, and potential reputation risks contribute to a negative perception of the manufacturer's sustainability credibility, potentially influencing supplier decisions and relationships.
74	B_{11}^{SMSC}-B_8^{SMSC}	Lack of synchronization in environmental competencies impacts fear of failure for sustainable collaboration adoption.	The lack of synchronization in environmental competencies heightens the fear of failure when considering sustainable collaboration adoption. Uncertainty, limited collaboration potential, reputational concerns, and missed opportunities for improvement contribute to this fear, hindering the willingness to embrace and invest in sustainable collaboration initiatives.
75	B_{12}^{SMSC}-B_2^{SMSC}	Lack of joint planning for recycling impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	The lack of joint planning for recycling negatively impacts the sustainability credibility of manufacturers as perceived by their suppliers by indicating a disregard for comprehensive recycling practices, inefficient resource utilization, and a missed opportunity to contribute to a sustainable environment, leading to a diminished perception of the manufacturer's commitment to sustainability.
76	B_{12}^{SMSC}-B_5^{SMSC}	Lack of joint planning for recycling impacts lack of joint planning to manage the environmental management system.	The lack of joint planning for recycling can have a cascading effect, leading to a lack of joint planning to manage the environmental management system. The absence of collaboration and coordination in recycling efforts and missed synergies can undermine the effectiveness and coherence of the overall environmental management approach.
77	B_{12}^{SMSC}-B_8^{SMSC}	Lack of joint planning for recycling impacts fear of failure for sustainable collaboration adoption.	Lack of joint planning for recycling can amplify the fear of failure in adopting sustainable collaboration, as without clear strategies and coordination, the potential for inefficiency, confusion, and unsuccessful outcomes increases, leading to a reluctance to engage in such collaborations.
78	B_{13}^{SMSC}-B_2^{SMSC}	Lack of combined training programs impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	A lack of combined training programs can negatively impact the sustainability credibility of manufacturers in the eyes of their suppliers. Without shared knowledge and skills regarding sustainability practices, manufacturers may struggle to implement effective sustainability measures, leading to a perception of poor credibility among suppliers who value sustainability as a critical aspect of their partnerships.
79	B_{13}^{SMSC}-B_4^{SMSC}	Lack of combined training programs impacts misaligned practices for pollution prevention between manufacturer and supplier.	The lack of combined training programs can result in misaligned practices for pollution prevention between manufacturers and suppliers. Without a shared understanding of pollution prevention strategies and protocols, manufacturers and suppliers may have different approaches and levels of commitment to reducing pollution. This misalignment can lead to inconsistencies in environmental practices, hinder collaboration, and potentially undermine efforts to achieve effective pollution prevention throughout the supply chain.
80	B_{13}^{SMSC}-B_5^{SMSC}	Lack of combined training programs impacts lack of joint planning to manage the environmental management system.	When manufacturers and suppliers do not have access to shared training and knowledge, they may struggle to align their efforts and effectively coordinate the implementation of an environmental management system. This can result in inefficiencies, inconsistencies, and a reduced ability to collaboratively address environmental challenges, ultimately hindering the overall effectiveness of the environmental management system.

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S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
81	B_{13}^{SMSC}-B_{6}^{SMSC}	Lack of combined training programs impacts lack of coordination for pollution controls between suppliers and manufacturer.	Without shared training and knowledge regarding pollution control measures, suppliers and manufacturers may have differing approaches and standards for addressing environmental impacts. This lack of coordination can result in gaps, overlaps, or inconsistent practices in pollution control efforts, diminishing the overall effectiveness of environmental management and potentially leading to increased environmental harm.
82	B_{13}^{SMSC}-B_{8}^{SMSC}	Lack of combined training programs impacts fear of failure for sustainable collaboration adoption.	Without shared training and knowledge, manufacturer and supplier may lack the necessary skills and understanding to effectively engage in sustainable collaboration. This can create uncertainty, increase the risk of unsuccessful outcomes, and ultimately amplify the fear of failure, discouraging organizations from actively participating in sustainable collaboration efforts.
83	B_{13}^{SMSC}-B_{10}^{SMSC}	Lack of combined training programs impacts lack of collaborative efforts in return handling and waste material treatment.	The absence of shared training and knowledge among stakeholders can result in diverse approaches, practices, and comprehension regarding the sustainable handling of returns and waste materials. This lack of coordination can give rise to inefficiencies, inconsistent practices, and missed chances for collaboration in developing creative and sustainable solutions for the management of returns and waste materials.
84	B_{13}^{SMSC}-B_{11}^{SMSC}	Lack of combined training programs impacts lack of synchronization in environmental competencies.	Without shared training initiatives, stakeholders may possess varying levels of knowledge and skills in environmental practices and regulations. This lack of synchronization can hinder effective communication, collaboration, and coordination among stakeholders, potentially leading to inconsistencies in environmental competencies and a fragmented approach to addressing environmental challenges.
85	B_{13}^{SMSC}-B_{12}^{SMSC}	Lack of combined training programs impacts lack of joint planning for recycling.	Without shared training initiatives, stakeholders may have differing levels of understanding and expertise in recycling practices, regulations, and strategies. This can lead to a lack of coordination, inconsistent approaches, and missed opportunities for collaborative planning in recycling efforts. A lack of joint planning can hinder the development of efficient and effective recycling systems, impede progress towards sustainability goals, and limit the overall impact of recycling initiatives.
86	B_{13}^{SMSC}-B_{14}^{SMSC}	Lack of combined training programs impacts lack of collaborative actions for employment practices.	Without shared training initiatives, stakeholders may have differing knowledge and understanding of best practices in employment, such as diversity and inclusion, fair labor practices, or employee well-being. This lack of collaboration can lead to inconsistencies, disparities, and missed opportunities for collective efforts to improve employment practices. It can hinder the establishment of cohesive and impactful initiatives aimed at creating positive and sustainable work environments.
87	B_{13}^{SMSC}-B_{15}^{SMSC}	Lack of combined training programs impacts lack of sharing responsibilities for interests and rights of employees.	The absence of shared training initiatives between manufacturer and supplier can result in differing levels of awareness and comprehension regarding employee interests and rights, including fair treatment, equal opportunities, and workplace safety. This can contribute to a lack of coordination and collaboration in safeguarding and promoting these interests and rights, potentially leading to disparities, unequal treatment, and missed opportunities for collective action aimed at ensuring the well-being of employees.
88	B_{13}^{SMSC}-B_{16}^{SMSC}	Lack of combined training programs impacts lack of sharing responsibilities for worker health and safety.	Without shared training initiatives, stakeholders may have varying levels of knowledge and understanding of work health and safety practices, regulations, and protocols. This can result in a lack of coordination and collaboration in upholding and sharing responsibilities for ensuring a safe work environment. It may lead to inconsistencies, increased risks, and missed opportunities for collective action to promote and prioritize the health and safety of employees.
89	B_{13}^{SMSC}-B_{17}^{SMSC}	Lack of combined training programs impacts lack of joint planning to manage occupational health and safety management system.	The absence of shared training initiatives among stakeholders can result in varying levels of knowledge and skills concerning occupational health and safety practices and regulations. This lack of coordination can hinder effective collaboration and communication when establishing and executing a comprehensive occupational health and safety management system. Consequently, it can lead to inconsistencies, inadequate coverage, and missed chances for collective planning and enhancing workplace safety standards.
90	B_{13}^{SMSC}-B_{19}^{SMSC}	Lack of combined training programs impacts lack of consistent and adequate performance measurement system.	Without shared training initiatives, stakeholders may have differing understandings and methodologies for measuring performance in various areas. This lack of coordination can result in inconsistencies, discrepancies, and a lack of standardized approaches when assessing performance. It may also lead to inadequate measurement practices that fail to capture the full scope of performance indicators, hindering effective evaluation and improvement efforts.
91	B_{14}^{SMSC}-B_{2}^{SMSC}	Lack of collaborative actions for employment practices impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	When manufacturers fail to actively engage in collaborative efforts to improve employment practices, such as fair labor practices, diversity and inclusion, and employee well-being, it can create doubts among suppliers about the manufacturer's commitment to sustainability. Suppliers who prioritize sustainable partnerships may perceive the manufacturer as lacking credibility in sustainability, which can weaken their trust and willingness to collaborate further.

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Table A.3 (*continued*)

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
92	B_{14}^{SMSC}-B_{8}^{SMSC}	Lack of collaborative actions for employment practices impacts fear of failure for sustainable collaboration adoption.	When manufacturer and supplier do not actively engage in collaborative efforts to improve employment practices, such as fair treatment, equal opportunities, and employee well-being, it creates uncertainty and doubt regarding the success of sustainable collaboration initiatives. The fear of failure arises as the lack of collaboration undermines the effectiveness and credibility of sustainable collaboration, reducing motivation and confidence in pursuing such endeavors.
93	B_{14}^{SMSC}-B_{15}^{SMSC}	Lack of collaborative actions for employment practices impacts lack of sharing responsibilities for interests and rights of employees.	When manufacturer and supplier fail to actively collaborate on matters such as fair treatment, equal opportunities, and employee rights, it hinders the collective effort to ensure the well-being and protection of employees. The absence of collaboration in sharing responsibilities for these interests and rights can lead to a fragmented approach, inconsistencies, and missed opportunities to collectively advocate for and safeguard the rights and well-being of employees.
94	B_{14}^{SMSC}-B_{16}^{SMSC}	Lack of collaborative actions for employment practices impacts lack of sharing responsibilities for worker health and safety.	The absence of active collaboration between manufacturer and supplier regarding workplace safety undermines the collective effort to establish a safe working environment. This lack of collaboration in sharing responsibilities for worker health and safety leads to inconsistencies, gaps in coverage, and missed opportunities to collectively address and enhance safety standards. Consequently, there is an increased risk of inadequate safety measures that can potentially jeopardize the well-being of employees.
95	B_{14}^{SMSC}-B_{17}^{SMSC}	Lack of collaborative actions for employment practices impacts lack of joint planning to manage occupational health and safety management system.	When manufacturer and supplier do not actively collaborate on employment practices, such as fair treatment, employee well-being, and safety, it hampers the collective effort to develop and implement an effective occupational health and safety management system. The absence of collaboration in joint planning can lead to inconsistencies, gaps in coverage, and missed opportunities to collectively address and improve occupational health and safety.
96	B_{15}^{SMSC}-B_{2}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	When manufacturers fail to actively share responsibilities for employee interests and rights, it raises concerns about their commitment to sustainable practices. Suppliers who prioritize sustainable partnerships may view the manufacturer as lacking credibility in sustainability, which can diminish trust and lead to a perception of poor sustainability practices. This can affect the supplier's willingness to continue working with the manufacturer and can have broader reputational implications.
97	B_{15}^{SMSC}-B_{8}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees impacts fear of failure for sustainable collaboration adoption.	The lack of sharing responsibilities for employee interests and rights intensifies the fear of failure in adopting sustainable collaboration, as it signals a disregard for crucial aspects of sustainability and undermines the trust and confidence necessary for successful collaboration.
98	B_{15}^{SMSC}-B_{14}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees impacts lack of collaborative actions for employment practices.	When manufacturer and supplier do not actively share responsibilities, it hampers collective efforts to improve employment practices such as fair treatment, equal opportunities, and employee well-being. This lack of collaboration undermines the development of comprehensive and effective employment practices, hindering progress towards creating a positive and sustainable work environment.
99	B_{15}^{SMSC}-B_{16}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees impacts lack of sharing responsibilities for worker health and safety.	When manufacturer and supplier fail to collaborate in ensuring employee well-being, it hampers the collective effort to establish and maintain a safe working environment, resulting in a fragmented approach and increased risks to workplace health and safety.
100	B_{15}^{SMSC}-B_{17}^{SMSC}	Lack of sharing responsibilities for interests and rights of employees impacts lack of joint planning to manage occupational health and safety management system.	When manufacturer and supplier do not collaborate in addressing employee concerns, it hampers the collective effort to develop and implement an effective occupational health and safety management system, resulting in a fragmented approach and potential gaps in ensuring workplace safety.
101	B_{16}^{SMSC}-B_{2}^{SMSC}	Lack of sharing responsibilities for worker health and safety impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	When manufacturers do not actively share responsibilities for ensuring workplace health and safety, it raises concerns about their commitment to sustainability and employee well-being. This lack of collaboration diminishes the manufacturer's credibility in sustainability, leading to a negative perception among suppliers and potentially affecting the supplier's willingness to continue working with them.
102	B_{16}^{SMSC}-B_{8}^{SMSC}	Lack of sharing responsibilities for worker health and safety impacts fear of failure for sustainable collaboration adoption.	When manufacturer and supplier fail to collaborate in ensuring workplace health and safety, it raises concerns about the effectiveness and commitment to sustainable practices. This lack of collaboration undermines the trust and confidence necessary for successful collaboration, heightening the fear of failure in adopting sustainable collaboration initiatives.
103	B_{16}^{SMSC}-B_{14}^{SMSC}	Lack of sharing responsibilities for worker health and safety impacts lack of collaborative actions for employment practices.	When manufacturer and supplier do not actively collaborate on workplace health and safety, it creates a fragmented approach and hampers collective efforts to improve broader employment practices, such as fair treatment, employee well-being, and equal opportunities.

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Table A.3 (*continued*)

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
104	B_{16}^{SMSC}-B_{15}^{SMSC}	Lack of sharing responsibilities for worker health and safety impacts lack of sharing responsibilities for interests and rights of employees.	The absence of active collaboration between manufacturer and supplier in ensuring workplace health and safety creates a disconnect in addressing the broader interests and rights of employees, including fair treatment, equal opportunities, and well-being. This lack of collaboration impedes the collective endeavor to promote and protect employee interests and rights, resulting in the possibility of disparities and missed opportunities for comprehensive support and advocacy.
105	B_{16}^{SMSC}-B_{17}^{SMSC}	Lack of sharing responsibilities for worker health and safety impacts lack of joint planning to manage occupational health and safety management system.	When manufacturer and supplier do not actively collaborate on worker health and safety, it creates a disconnect in coordinating efforts and sharing responsibilities to develop and implement an effective occupational health and safety management system. This lack of collaboration hampers the collective planning and coordination required for managing and improving workplace safety standards, potentially leading to inconsistencies, gaps, and missed opportunities for comprehensive management.
106	B_{17}^{SMSC}-B_{2}^{SMSC}	Lack of joint planning to manage occupational health and safety management system impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	The lack of joint planning to manage the occupational health and safety management system diminishes the sustainability credibility of a manufacturer as perceived by their suppliers. It creates doubts about the manufacturer's commitment to sustainable practices and employee well-being, leading to a negative perception and potential erosion of trust from suppliers.
107	B_{17}^{SMSC}-B_{8}^{SMSC}	Lack of joint planning to manage occupational health and safety management system impacts fear of failure for sustainable collaboration adoption.	The lack of joint planning to manage the occupational health and safety management system intensifies the fear of failure in adopting sustainable collaboration. It creates uncertainties and doubts about the effectiveness and commitment to occupational health and safety, undermining confidence in the success of sustainable collaboration initiatives.
108	B_{17}^{SMSC}-B_{14}^{SMSC}	Lack of joint planning to manage occupational health and safety management system impacts lack of collaborative actions for employment practices.	The lack of joint planning to manage the occupational health and safety management system hinders collaborative actions for employment practices. Without coordinated planning, it becomes challenging to align efforts and address broader employment concerns, such as fair treatment and employee well-being, limiting the potential for effective collaboration in improving workplace conditions.
109	B_{17}^{SMSC}-B_{15}^{SMSC}	Lack of joint planning to manage occupational health and safety management system impacts lack of sharing responsibilities for interests and rights of employees.	The lack of joint planning to manage the occupational health and safety management system contributes to a lack of sharing responsibilities for the interests and rights of employees. Without coordinated planning, there is a diminished focus on addressing employee concerns and ensuring their well-being, resulting in a fragmented approach and potential neglect of employee interests and rights.
110	B_{17}^{SMSC}-B_{16}^{SMSC}	Lack of joint planning to manage occupational health and safety management system impacts lack of sharing responsibilities for worker health and safety.	The lack of joint planning to manage the occupational health and safety management system leads to a lack of sharing responsibilities for work health and safety. Without coordinated planning, there is a lack of clear accountability and shared ownership, resulting in gaps and inconsistencies in ensuring a safe working environment.
111	B_{18}^{SMSC}-B_{1}^{SMSC}	Lack of top management involvement impacts lack of manufacturer-supplier communications for sustainable standards and appropriate regulations.	The lack of top management involvement hampers manufacturer-supplier communications regarding sustainable standards and appropriate regulations, resulting in a lack of alignment, coordination, and shared understanding, which can impede the implementation and adherence to sustainable practices.
112	B_{18}^{SMSC}-B_{2}^{SMSC}	Lack of top management involvement impacts poor sustainability credibility of manufacturer as perceived by their suppliers.	When top management fails to actively engage in sustainability initiatives, it raises doubts about the manufacturer's commitment to sustainable practices, leading to a diminished perception of their sustainability credibility among suppliers. This can affect the supplier's trust, willingness to collaborate, and overall perception of the manufacturer's sustainability performance.
113	B_{18}^{SMSC}-B_{3}^{SMSC}	Lack of top management involvement impacts lack of trust between manufacturer and supplier.	When top management is not actively engaged in the relationship, it can lead to a perception of indifference or lack of commitment to the partnership, which erodes trust. The absence of top management involvement may result in a lack of communication, accountability, and alignment, leading to doubts about the manufacturer's reliability and long-term commitment, negatively impacting the trust between the manufacturer and the supplier.
114	B_{18}^{SMSC}-B_{4}^{SMSC}	Lack of top management involvement impacts misaligned practices for pollution prevention between manufacturer and supplier.	Without active leadership and coordination from top management, there may be a lack of clear direction, communication, and shared goals regarding pollution prevention. This can result in inconsistent approaches, differing priorities, and missed opportunities for collaborative efforts in mitigating pollution and implementing effective environmental practices.
115	B_{18}^{SMSC}-B_{5}^{SMSC}	Lack of top management involvement impacts lack of joint planning to manage the environmental management system.	Without active participation from top management, there is a lack of strategic direction, coordination, and commitment, leading to difficulties in establishing a comprehensive and effective environmental management system.
116	B_{18}^{SMSC}-B_{6}^{SMSC}	Lack of top management involvement impacts lack of coordination for pollution controls between suppliers and manufacturer.	Without active leadership and oversight, there may be limited communication, alignment, and shared responsibility for implementing pollution control measures, leading to inconsistencies, gaps, and missed opportunities for effective collaboration in managing and reducing pollution throughout the supply chain.

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Table A.3 (*continued*)

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
117	B_{18}^{SMSC}-B_{7}^{SMSC}	Lack of top management involvement impacts lack of scope and focus for sustainable collaboration.	Without active participation and direction from top management, there may be ambiguity in the objectives, limited resources allocated, and a lack of strategic guidance, hindering the development and implementation of meaningful and impactful sustainable collaboration initiatives.
118	B_{18}^{SMSC}-B_{8}^{SMSC}	Lack of top management involvement impacts fear of failure for sustainable collaboration adoption.	Without visible support and commitment from top management, there is a perceived lack of organizational priority and resources, which undermines confidence in the success and long-term viability of sustainable collaboration initiatives, increasing the fear of failure among stakeholders.
119	B_{18}^{SMSC}-B_{9}^{SMSC}	Lack of top management involvement impacts unwillingness to share risks and rewards.	When top management is not actively involved, there may be a lack of clear direction and accountability, leading to a reluctance in sharing risks and rewards, as stakeholders may feel uncertain about the commitment and support from the organization's leadership.
120	B_{18}^{SMSC}-B_{10}^{SMSC}	Lack of top management involvement impacts lack of collaborative efforts in return handling and waste material treatment.	Lack of top management involvement in return handling and waste material treatment hinders the establishment of a collaborative environment, resulting in inefficient processes and limited coordination between departments, leading to suboptimal handling and treatment outcomes.
121	B_{18}^{SMSC}-B_{11}^{SMSC}	Lack of top management involvement impacts lack of synchronization in environmental competencies.	Lack of top management involvement in environmental competencies leads to a lack of synchronization among departments, resulting in inconsistent strategies and practices, hampering overall environmental performance and sustainability goals.
122	B_{18}^{SMSC}-B_{12}^{SMSC}	Lack of top management involvement impacts lack of joint planning for recycling.	Lack of top management involvement in joint planning for recycling can result in a lack of coordination and collaboration among different departments and stakeholders. This can lead to inefficiencies, missed opportunities, and inadequate resource allocation, hindering the development of effective recycling strategies and initiatives.
123	B_{18}^{SMSC}-B_{13}^{SMSC}	Lack of top management involvement impacts lack of combined training programs.	Lack of top management involvement in combined training programs can result in a lack of standardized and comprehensive training for employees across different departments. This can lead to inconsistent skill sets, knowledge gaps, and a lack of synergy in operations, hindering overall organizational performance and productivity.
124	B_{18}^{SMSC}-B_{14}^{SMSC}	Lack of top management involvement impacts lack of collaborative actions for employment practices.	Lack of top management involvement in collaborative actions for employment practices can result in a lack of coordination and alignment among different departments and stakeholders. This can lead to inconsistent employment policies, miscommunication, and a fragmented approach to human resources, hindering employee satisfaction, productivity, and overall organizational success.
125	B_{18}^{SMSC}-B_{15}^{SMSC}	Lack of top management involvement impacts lack of sharing responsibilities for interests and rights of employees.	Lack of top management involvement in sharing responsibilities for the interests and rights of employees can result in a lack of accountability and neglect of employee welfare. This can lead to dissatisfaction, low morale, and potential violations of employee rights, undermining the overall work environment and organizational culture.
126	B_{18}^{SMSC}-B_{16}^{SMSC}	Lack of top management involvement impacts lack of sharing responsibilities for worker health and safety.	Lack of top management involvement in sharing responsibilities for worker health and safety can result in a disregard for safety protocols and a lack of emphasis on creating a safe working environment. This can lead to increased risks, accidents, and injuries, negatively impacting employee well-being, productivity, and overall organizational reputation.
127	B_{18}^{SMSC}-B_{17}^{SMSC}	Lack of top management involvement impacts lack of joint planning to manage occupational health and safety management system.	Lack of top management involvement in joint planning to manage the occupational health and safety management system can result in a lack of direction and coordination in implementing effective safety measures. This can lead to inconsistent policies, inadequate hazard identification and control, and a higher risk of workplace accidents and injuries, jeopardizing the well-being of employees and the organization's compliance with safety regulations.
128	B_{18}^{SMSC}-B_{19}^{SMSC}	Lack of top management involvement impacts lack of consistent and adequate performance measurement system.	Lack of top management involvement in establishing a consistent and adequate performance measurement system results in a lack of clarity, accountability, and benchmarking. This leads to difficulty in tracking progress, identifying areas for improvement, and making informed decisions to enhance overall organizational performance.
129	B_{19}^{SMSC}-B_{4}^{SMSC}	Lack of consistent and adequate performance measurement system impacts misaligned practices for pollution prevention between manufacturer and supplier.	The lack of a consistent and adequate performance measurement system can result in misaligned practices for pollution prevention between manufacturers and suppliers. Without clear metrics and benchmarks, there is a higher likelihood of differing priorities, inconsistent standards, and a lack of effective collaboration to address pollution prevention, hampering environmental sustainability efforts.
130	B_{19}^{SMSC}-B_{5}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of joint planning to manage the environmental management system.	Lack of a consistent and adequate performance measurement system impacts joint planning to manage the environmental management system by hindering effective coordination, monitoring, and evaluation of environmental performance. Without proper metrics and benchmarks, there is a lack of alignment, accountability, and strategic decision-making, which can impede the establishment of robust environmental management practices and hinder overall environmental sustainability goals.

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Table A.3 (*continued*)

S. N.	Relation	Paired comparison of Barriers	Interpretation - In what way will barriers impact other barriers?
131	B_{19}^{SMSC}-B_{6}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of coordination for pollution controls between suppliers and manufacturer.	Without clear metrics and benchmarks, there is a higher likelihood of differing standards, miscommunication, and a lack of effective collaboration, leading to inconsistent pollution control practices and potential environmental risks.
132	B_{19}^{SMSC}-B_{8}^{SMSC}	Lack of consistent and adequate performance measurement system impacts fear of failure for sustainable collaboration adoption.	The lack of a consistent and adequate performance measurement system increases the fear of failure when adopting sustainable collaboration practices. Without proper metrics to track progress and demonstrate success, stakeholders may be hesitant to embrace collaborative initiatives, fearing potential reputational risks or uncertainties about the effectiveness of sustainability efforts.
133	B_{19}^{SMSC}-B_{10}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of collaborative efforts in return handling and waste material treatment.	Without clear metrics to assess performance, there is a lack of accountability, coordination, and motivation for effective collaboration, resulting in suboptimal handling and treatment of returns and waste materials.
134	B_{19}^{SMSC}-B_{11}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of synchronization in environmental competencies.	Without proper metrics and benchmarks, there is a limited ability to assess and align environmental competencies across departments, hindering the development of a cohesive and effective environmental management approach.
135	B_{19}^{SMSC}-B_{12}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of joint planning for recycling.	The lack of a consistent and adequate performance measurement system hampers joint planning for recycling. Without clear metrics and benchmarks, there is a limited ability to coordinate and align recycling initiatives, resulting in fragmented efforts, missed opportunities, and suboptimal recycling outcomes.
136	B_{19}^{SMSC}-B_{13}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of combined training programs.	Without proper metrics to evaluate training effectiveness, there is a diminished incentive to develop and implement comprehensive training initiatives, leading to inconsistent skill development and limited knowledge sharing among employees.
137	B_{19}^{SMSC}-B_{14}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of collaborative actions for employment practices.	Without clear metrics to assess the effectiveness of collaborative efforts, there is a reduced incentive for departments and stakeholders to work together, resulting in fragmented employment practices and limited collaboration in improving overall employee satisfaction and well-being.
138	B_{19}^{SMSC}-B_{15}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of sharing responsibilities for interests and rights of employees.	The absence of well-defined metrics and benchmarks for evaluating and monitoring progress diminishes the emphasis on safeguarding the welfare and rights of employees, potentially resulting in negligence and insufficient measures to protect their interests.
139	B_{19}^{SMSC}-B_{16}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of sharing responsibilities for worker health and safety.	Without clear metrics and benchmarks to assess and monitor safety performance, there is a reduced focus on collectively shouldering the responsibility, leading to potential gaps, complacency, and inadequate measures to ensure a safe work environment.
140	B_{19}^{SMSC}-B_{17}^{SMSC}	Lack of consistent and adequate performance measurement system impacts lack of joint planning to manage occupational health and safety management system.	Without clear metrics and benchmarks, there is a limited ability to coordinate efforts, set targets, and evaluate the effectiveness of safety management practices, resulting in fragmented planning and potential gaps in ensuring the well-being of employees.

Table A.4
FRM of barriers

	B_1^{SMSC}	B_2^{SMSC}	B_3^{SMSC}	B_4^{SMSC}	B_5^{SMSC}	B_6^{SMSC}	B_7^{SMSC}	B_8^{SMSC}	B_9^{SMSC}	B_{10}^{SMSC}	B_{11}^{SMSC}	B_{12}^{SMSC}	B_{13}^{SMSC}	B_{14}^{SMSC}	B_{15}^{SMSC}	B_{16}^{SMSC}	B_{17}^{SMSC}	B_{18}^{SMSC}	B_{19}^{SMSC}	Driving power
B_1^{SMSC}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
B_2^{SMSC}	0	1	0	1	**1**	**1**	1	1	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	0	**1**	16
B_3^{SMSC}	1	1	1	**1**	**1**	**1**	**1**	1	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	19
B_4^{SMSC}	0	1	0	1	1	1	**1**	1	**1**	**1**	**1**	**1**	0	0	0	0	0	0	0	10
B_5^{SMSC}	0	1	0	1	1	1	**1**	1	**1**	1	1	1	0	0	0	0	0	0	0	10
B_6^{SMSC}	0	1	0	1	1	1	**1**	1	**1**	**1**	**1**	**1**	0	0	0	0	0	0	0	10
B_7^{SMSC}	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**1**	1	19
B_8^{SMSC}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
B_9^{SMSC}	1	**1**	**1**	1	1	1	**1**	1	1	1	1	1	1	1	1	1	1	**1**	**1**	19
B_{10}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	1	0	0	0	0	0	0	0	0	0	6
B_{11}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	0	1	0	0	0	0	0	0	0	0	6
B_{12}^{SMSC}	0	1	0	**1**	1	**1**	**1**	1	**1**	0	0	1	0	0	0	0	0	0	0	8
B_{13}^{SMSC}	0	1	0	1	1	1	**1**	1	**1**	1	1	1	1	1	1	1	1	**1**	1	17
B_{14}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	0	0	0	0	1	1	1	1	0	0	9
B_{15}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	0	0	0	0	1	1	1	1	0	0	9
B_{16}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	0	0	0	0	1	1	1	1	0	0	9
B_{17}^{SMSC}	0	1	0	**1**	0	0	**1**	1	**1**	0	0	0	0	1	1	1	1	0	0	9
B_{18}^{SMSC}	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19
B_{19}^{SMSC}	**1**	**1**	0	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	15
Dependence power	6	18	5	18	12	12	17	19	17	12	12	12	8	12	12	12	12	6	8	

Table A.5
Interpretation of significant transitive links

S. No.	Transitive link	Interpretation
1	$B_3^{SMSC} - B_{13}^{SMSC}(B_3^{SMSC} - B_9^{SMSC} - B_{13}^{SMSC})$	Lack of trust between a manufacturer and supplier can negatively impact the development of combined training programs due to their unwillingness to share risks and rewards. The absence of trust creates barriers to collaboration and hampers the willingness to invest in joint training initiatives, leading to a lack of shared resources, knowledge, and coordination in developing comprehensive training programs.
2	$B_3^{SMSC} - B_{19}^{SMSC}(B_3^{SMSC} - B_1^{SMSC} - B_{19}^{SMSC})$	Lack of trust between a manufacturer and supplier can lead to a lack of consistent and adequate performance measurement system due to insufficient communication regarding sustainable standards and appropriate regulations. The absence of trust hinders open dialogue, inhibiting the sharing of information necessary for establishing common performance metrics, resulting in a fragmented approach to measuring and evaluating sustainability efforts between the manufacturer and supplier.
3	$B_3^{SMSC} - B_{18}^{SMSC}(B_3^{SMSC} - B_1^{SMSC} - B_{18}^{SMSC})$	Lack of trust between a manufacturer and supplier can result in a lack of top management involvement due to insufficient communication regarding sustainable standards and appropriate regulations. The lack of trust undermines collaboration and transparency, leading to limited engagement from top management in jointly addressing sustainability concerns and implementing effective practices, ultimately hindering the overall progress towards sustainable goals.
4	$B_3^{SMSC} - B_7^{SMSC}(B_3^{SMSC} - B_1^{SMSC} - B_7^{SMSC})$	Lack of trust between a manufacturer and supplier can lead to a lack of scope and focus for sustainable collaboration due to insufficient communication regarding sustainable standards and appropriate regulations. The absence of trust inhibits effective collaboration, making it challenging to establish shared goals, align priorities, and define the scope of sustainable initiatives, resulting in a fragmented and less impactful approach to collaboration for sustainability between the manufacturer and supplier.
5	$B_7^{SMSC} - B_1^{SMSC}(B_7^{SMSC} - B_3^{SMSC} - B_1^{SMSC})$	Lack of scope and focus for sustainable collaboration can contribute to a lack of manufacturer-supplier communications for sustainable standards and appropriate regulations due to the underlying lack of trust between the parties. Without a clear direction and shared goals, there is limited motivation and incentive to engage in open and effective communication, hindering the establishment of robust channels for discussing and aligning on sustainable standards and regulatory compliance.
6	$B_7^{SMSC} - B_{18}^{SMSC}(B_7^{SMSC} - B_3^{SMSC} - B_{18}^{SMSC})$	Lack of scope and focus for sustainable collaboration can result in a lack of top management involvement due to the underlying lack of trust between the manufacturer and supplier. Without a clear direction and shared goals for sustainability, there is limited motivation for top management to actively engage in collaborative efforts, leading to reduced involvement, less dedicated resources, and a missed opportunity to drive meaningful sustainability initiatives within the organization.
7	$B_9^{SMSC} - B_3^{SMSC}(B_9^{SMSC} - B_1^{SMSC} - B_3^{SMSC})$	The unwillingness to share risks and rewards can create a lack of trust between a manufacturer and supplier, further exacerbated by the absence of communication regarding sustainable standards and appropriate regulations. When manufacturer and supplier are hesitant to collaborate and share the potential benefits and risks associated with sustainable initiatives, it hampers open dialogue, erodes trust, and impairs effective communication channels, ultimately hindering the development of shared understanding and cooperation on sustainability matters between the manufacturer and supplier.
8	$B_9^{SMSC} - B_7^{SMSC}(B_9^{SMSC} - B_1^{SMSC} - B_7^{SMSC})$	The unwillingness to share risks and rewards can contribute to a lack of scope and focus for sustainable collaboration due to the resulting lack of communication between the manufacturer and supplier regarding sustainable standards and appropriate regulations. When there is a reluctance to share the potential risks and rewards associated with sustainable initiatives, it hampers effective communication channels, limiting discussions on defining the scope and focus of collaborative efforts for sustainability. This lack of shared understanding and alignment can hinder the development of comprehensive and impactful sustainable collaboration between the manufacturer and supplier.
9	$B_9^{SMSC} - B_{18}^{SMSC}(B_9^{SMSC} - B_1^{SMSC} - B_{18}^{SMSC})$	The unwillingness to share risks and rewards can impact the lack of top management involvement due to the resulting lack of manufacturer-supplier communications regarding sustainable standards and appropriate regulations. When there is a reluctance to collaborate and share the potential risks and rewards associated with sustainability, it creates a barrier to effective communication and engagement between top management and the manufacturer-supplier partnership. This unwillingness diminishes the incentive for top management to actively participate and invest resources in driving sustainable initiatives, leading to a lack of involvement and reduced commitment to sustainability efforts within the organization.
10	$B_9^{SMSC} - B_{19}^{SMSC}(B_9^{SMSC} - B_1^{SMSC} - B_{19}^{SMSC})$	The unwillingness to share risks and rewards can impact the lack of a consistent and adequate performance measurement system due to the resulting lack of communication between the manufacturer and supplier regarding sustainable standards and appropriate regulations. When there is an unwillingness to collaborate and share the potential risks and rewards associated with sustainability, it hampers effective communication channels, making it difficult to establish common metrics and benchmarks for measuring performance. This lack of shared understanding and alignment impedes the development of a comprehensive and robust performance measurement system, hindering the ability to track and evaluate sustainability efforts effectively.
11	$B_{13}^{SMSC} - B_7^{SMSC}(B_{13}^{SMSC} - B_1^{SMSC} - B_7^{SMSC})$	Lack of combined training programs can impact the lack of scope and focus for sustainable collaboration due to the resulting lack of communication between the manufacturer and supplier regarding sustainable standards and appropriate regulations. When there is a lack of comprehensive training programs that involve both the manufacturer and supplier, it leads to a limited understanding of sustainable practices, standards, and regulations. This lack of knowledge and awareness hinders effective communication and collaboration, limiting the scope and focus of sustainable initiatives and impeding the development of a cohesive and impactful collaboration for sustainability between the manufacturer and supplier.
12	$B_{13}^{SMSC} - B_9^{SMSC}(B_{13}^{SMSC} - B_1^{SMSC} - B_9^{SMSC})$	The lack of combined training programs can contribute to an unwillingness to share risks and rewards due to the resulting lack of communication between the manufacturer and supplier regarding sustainable standards and appropriate regulations. When there is a deficiency in comprehensive training programs that involve both parties, it can lead to limited understanding and knowledge of sustainable practices and regulations. This lack of shared knowledge and awareness can create hesitance to share risks and rewards, as there may be a lack of confidence and alignment in sustainability goals and strategies. Consequently, it hampers effective communication, collaboration, and the willingness to engage in shared responsibilities for sustainable outcomes between the manufacturer and supplier.
13	$B_{13}^{SMSC} - B_{18}^{SMSC}(B_{13}^{SMSC} - B_1^{SMSC} - B_{18}^{SMSC})$	The lack of combined training programs can contribute to a lack of top management involvement due to the resulting lack of communication between the manufacturer and supplier regarding sustainable standards and appropriate regulations. When there is a deficiency in comprehensive training programs that involve both parties, it limits the knowledge and understanding of sustainable practices and regulations among employees, including top management. This lack of shared knowledge and awareness can impede effective communication and collaboration between top management and the manufacturer-supplier partnership, reducing their involvement and commitment to sustainability initiatives.
14	$B_{19}^{SMSC} - B_1^{SMSC}(B_{19}^{SMSC} - B_{13}^{SMSC} - B_1^{SMSC})$	Lack of a consistent and adequate performance measurement system can impact the lack of manufacturer-supplier communications for sustainable standards and appropriate regulations due to the absence of combined training programs. When there is no reliable system in place to measure and assess sustainability performance, it creates a barrier to effective communication between the manufacturer and supplier. The lack of a standardized framework for evaluating sustainability outcomes makes it challenging to discuss and align on sustainable standards and regulations, further hindering the need for comprehensive combined training programs to address these gaps in knowledge and understanding.
15	$B_2^{SMSC} - B_5^{SMSC}(B_2^{SMSC} - B_4^{SMSC} - B_5^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of joint planning to manage the environmental management system due to misaligned practices for pollution prevention between the manufacturer and supplier. When suppliers perceive the manufacturer to have low credibility in sustainability efforts, it undermines trust and collaboration. This lack of trust

(*continued on next page*)

Table A.5 (continued).

No.	Transitive link	Interpretation
		and alignment in pollution prevention practices hampers joint planning, making it challenging to establish a coordinated and effective environmental management system that addresses shared environmental concerns.
16	$B_2^{SMSC} - B_6^{SMSC}(B_2^{SMSC} - B_4^{SMSC} - B_6^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of coordination for pollution controls between suppliers and the manufacturer due to misaligned practices for pollution prevention. When suppliers perceive the manufacturer to have low credibility in sustainability efforts, it creates a lack of trust and collaboration. This lack of trust hinders effective communication and coordination between suppliers and the manufacturer in implementing consistent and aligned pollution prevention practices, leading to fragmented efforts and potential environmental risks.
17	$B_2^{SMSC} - B_{14}^{SMSC}(B_2^{SMSC} - B_7^{SMSC} - B_{14}^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of collaborative actions for employment practices due to a lack of scope and focus for sustainable collaboration. When suppliers perceive the manufacturer to have low credibility in sustainability efforts, it undermines trust and reduces the willingness to engage in collaborative actions for employment practices. This lack of trust and alignment in sustainability goals limits the scope and focus of collaborative efforts, hindering the establishment of comprehensive and impactful employment practices that prioritize sustainability and the interests of employees.
18	$B_6^{SMSC} - B_{10}^{SMSC}(B_6^{SMSC} - B_5^{SMSC} - B_{10}^{SMSC})$	The lack of coordination for pollution controls between suppliers and the manufacturer can impact the lack of collaborative efforts in return handling and waste material treatment due to the absence of joint planning to manage the environmental management system. When there is a lack of coordination in pollution controls, it indicates a breakdown in communication and collaboration between suppliers and the manufacturer. This lack of coordination and joint planning hampers the establishment of an effective environmental management system, leading to fragmented efforts in return handling and waste material treatment, with suboptimal outcomes and a missed opportunity for collaborative improvements.
19	$B_6^{SMSC} - B_{11}^{SMSC}(B_6^{SMSC} - B_5^{SMSC} - B_{11}^{SMSC})$	The lack of coordination for pollution controls between suppliers and the manufacturer can impact the lack of synchronization in environmental competencies due to the absence of joint planning to manage the environmental management system. When there is a lack of coordination in pollution controls, it indicates a lack of alignment and collaboration between suppliers and the manufacturer in their environmental practices. This lack of coordination and joint planning hampers the synchronization of environmental competencies, resulting in inconsistent standards, practices, and knowledge gaps among the involved parties, hindering overall environmental performance and sustainability goals.
20	$B_{14}^{SMSC} - B_4^{SMSC}(B_{14}^{SMSC} - B_2^{SMSC} - B_4^{SMSC})$	The lack of collaborative actions for employment practices can impact misaligned practices for pollution prevention between the manufacturer and supplier, especially when there is poor sustainability credibility of the manufacturer as perceived by their suppliers. The absence of collaborative actions in employment practices signifies a limited commitment to sustainability and employee well-being. When suppliers perceive the manufacturer to have poor sustainability credibility, it erodes trust and hampers effective communication and cooperation. This lack of trust and alignment can lead to misaligned practices for pollution prevention, as the manufacturer and supplier may have divergent priorities and approaches to addressing sustainability concerns.
21	$B_6^{SMSC} - B_{12}^{SMSC}(B_6^{SMSC} - B_5^{SMSC} - B_{12}^{SMSC})$	The lack of coordination for pollution controls between suppliers and the manufacturer can impact the lack of joint planning for recycling due to the absence of joint planning to manage the environmental management system. When there is a lack of coordination in pollution controls, it indicates a breakdown in communication and collaboration between suppliers and the manufacturer. This lack of coordination and joint planning hampers the establishment of a cohesive approach to recycling, including efficient resource allocation, waste management strategies, and recycling initiatives. Without effective joint planning to manage the environmental management system, the recycling efforts may be disjointed, inconsistent, and less impactful in achieving sustainability goals.
22	$B_{15}^{SMSC} - B_4^{SMSC}(B_{15}^{SMSC} - B_2^{SMSC} - B_4^{SMSC})$	The lack of sharing responsibilities for the interests and rights of employees can impact misaligned practices for pollution prevention between the manufacturer and supplier, particularly when there is poor sustainability credibility of the manufacturer as perceived by their suppliers. When there is a lack of emphasis on employee interests and rights, it reflects a limited commitment to sustainability and ethical practices. This lack of shared responsibility and poor sustainability credibility can create a disconnect between the manufacturer and supplier in their approach to pollution prevention. The supplier, perceiving the manufacturer's lack of commitment, may be less motivated to align their own practices, resulting in misaligned efforts and potentially higher environmental impacts.
23	$B_2^{SMSC} - B_{15}^{SMSC}(B_2^{SMSC} - B_7^{SMSC} - B_{15}^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of sharing responsibilities for the interests and rights of employees due to the resulting lack of scope and focus for sustainable collaboration. When suppliers perceive the manufacturer to have low sustainability credibility, it erodes trust and reduces their willingness to engage in collaborative efforts. This lack of trust and alignment in sustainability goals can hinder the establishment of a comprehensive scope and focus for sustainable collaboration, leading to a limited emphasis on shared responsibilities for employee interests and rights. As a result, the manufacturer may be less motivated to address these aspects, which can negatively impact employee well-being and overall sustainability performance.
24	$B_{16}^{SMSC} - B_4^{SMSC}(B_{16}^{SMSC} - B_2^{SMSC} - B_4^{SMSC})$	The lack of sharing responsibilities for worker health and safety can impact misaligned practices for pollution prevention between the manufacturer and supplier, particularly when there is poor sustainability credibility of the manufacturer as perceived by their suppliers. When there is a lack of shared responsibilities for worker health and safety, it indicates a limited commitment to a safe and sustainable working environment. This lack of sharing responsibilities, combined with the poor sustainability credibility of the manufacturer, can erode trust and hinder effective communication and collaboration. As a result, the manufacturer and supplier may have divergent priorities and approaches to addressing pollution prevention, leading to misaligned practices and potentially increased environmental risks.
25	$B_2^{SMSC} - B_{16}^{SMSC}(B_2^{SMSC} - B_7^{SMSC} - B_{16}^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of sharing responsibilities for worker health and safety due to the resulting lack of scope and focus for sustainable collaboration. When suppliers perceive the manufacturer to have low sustainability credibility, it diminishes trust and reduces their willingness to actively engage in collaborative efforts. This lack of trust and alignment in sustainability goals can hinder the establishment of a comprehensive scope and focus for sustainable collaboration, including the sharing of responsibilities for worker health and safety. As a result, there may be limited communication and collaboration in addressing worker health and safety concerns, potentially leading to inadequate measures, increased risks, and a lack of shared responsibility for ensuring a safe working environment.
26	$B_{17}^{SMSC} - B_4^{SMSC}(B_{17}^{SMSC} - B_2^{SMSC} - B_4^{SMSC})$	The lack of joint planning to manage the occupational health and safety management system can impact misaligned practices for pollution prevention between the manufacturer and supplier, particularly when there is poor sustainability credibility of the manufacturer as perceived by their suppliers. When there is a lack of joint planning for occupational health and safety, it indicates a lack of coordination and collaboration between the manufacturer and supplier in addressing workplace safety concerns. This lack of joint planning, combined with the perception of poor sustainability credibility, can erode trust and hinder effective communication. As a result, the manufacturer and supplier may have differing priorities and approaches to pollution prevention, leading to misaligned practices and potentially increased environmental risks. The lack of joint planning exacerbates this misalignment, making it difficult to establish cohesive pollution prevention strategies and collaborative efforts.
27	$B_2^{SMSC} - B_{17}^{SMSC}(B_2^{SMSC} - B_7^{SMSC} - B_{17}^{SMSC})$	The poor sustainability credibility of a manufacturer, as perceived by their suppliers, can impact the lack of joint planning to manage the occupational health and safety management system due to the resulting lack of scope and focus for sustainable collaboration. When suppliers perceive the manufacturer to have low sustainability credibility, it diminishes trust and reduces their willingness to actively engage in joint planning efforts. This lack of trust and alignment in sustainability goals hampers the establishment of a comprehensive scope and focus for sustainable collaboration, including the management of the occupational health and safety system. As a result, there may be limited communication, coordination, and collaborative planning in addressing occupational health and safety concerns, leading to fragmented efforts and potentially inadequate measures to ensure a safe working environment.

Table A.6
Priority level of barriers Iteration-I

Barrier	Reachability set	Antecedent set	Intersection set	Level
B_1^{SMSC}	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18, 19	1, 3, 7, 9, 18, 19	
B_2^{SMSC}	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19	
B_3^{SMSC}	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18	1, 3, 7, 9, 18	
B_4^{SMSC}	2, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	2, 4, 5, 6, 7, 9, 10, 11, 12	
B_5^{SMSC}	2, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 9, 12	
B_6^{SMSC}	2, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 9, 12	
B_7^{SMSC}	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	
B_8^{SMSC}	8	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	8	I
B_9^{SMSC}	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	
B_{10}^{SMSC}	2, 4, 7, 8, 9, 10	1, 2, 3, 4, 5, 6, 7, 9, 10, 13, 18, 19	2, 4, 7, 9, 10	
B_{11}^{SMSC}	2, 4, 7, 8, 9, 11	1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 18, 19	2, 4, 7, 8, 9, 11	
B_{12}^{SMSC}	2, 4, 5, 6, 7, 8, 9, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 8, 9, 12	
B_{13}^{SMSC}	2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 7, 9, 13, 18, 19	2, 7, 9, 13, 18, 19	
B_{14}^{SMSC}	2, 4, 7, 8, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{15}^{SMSC}	2, 4, 7, 8, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{16}^{SMSC}	2, 4, 7, 8, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{17}^{SMSC}	2, 4, 7, 8, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{18}^{SMSC}	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_{19}^{SMSC}	1, 2, 4, 5, 6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 19	1, 2, 3, 7, 9, 13, 18, 19	1, 2, 13, 19	

Table A.7
Priority level of barriers Iteration-II

Barrier	Reachability set	Antecedent set	Intersection set	Level
B_1^{SMSC}	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18, 19	1, 3, 7, 9, 18, 19	
B_2^{SMSC}	2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19	II
B_3^{SMSC}	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18	1, 3, 7, 9, 18	
B_4^{SMSC}	2, 4, 5, 6, 7, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	2, 4, 5, 6, 7, 9, 10, 11, 12	II
B_5^{SMSC}	2, 4, 5, 6, 7, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 9, 12	
B_6^{SMSC}	2, 4, 5, 6, 7, 9, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 9, 12	
B_7^{SMSC}	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	
B_9^{SMSC}	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	
B_{10}^{SMSC}	2, 4, 7, 9, 10	1, 2, 3, 4, 5, 6, 7, 9, 10, 13, 18, 19	2, 4, 7, 9, 10	II
B_{11}^{SMSC}	2, 4, 7, 9, 11	1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 18, 19	2, 4, 7, 9, 11	II
B_{12}^{SMSC}	2, 4, 5, 6, 7, 9, 12	1, 2, 3, 4, 5, 6, 7, 9, 12, 13, 18, 19	2, 4, 5, 6, 7, 9, 12	II
B_{13}^{SMSC}	2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 2, 3, 7, 9, 13, 18, 19	2, 7, 9, 13, 18, 19	
B_{14}^{SMSC}	2, 4, 7, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{15}^{SMSC}	2, 4, 7, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{16}^{SMSC}	2, 4, 7, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{17}^{SMSC}	2, 4, 7, 9, 14, 15, 16, 17	1, 2, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	2, 7, 9, 14, 15, 16, 17	
B_{18}^{SMSC}	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_{19}^{SMSC}	1, 2, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 19	1, 2, 3, 7, 9, 13, 18, 19	1, 2, 13, 19	

Table A.8
Priority level of barriers Iteration-III

Barrier	Reachability set	Antecedent set	Intersection set	Level
B_1^{SMSC}	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18, 19	1, 3, 7, 9, 18, 19	
B_3^{SMSC}	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 18	1, 3, 7, 9, 18	
B_5^{SMSC}	5, 6, 7, 9	1, 3, 5, 6, 7, 9, 13, 18, 19	5, 6, 7, 9	III
B_6^{SMSC}	5, 6, 7, 9	1,3,5,6,7,9,13,18, 19	5, 6, 7, 9	III
B_7^{SMSC}	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18	
B_9^{SMSC}	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18	
B_{13}^{SMSC}	5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 13, 18, 19	7, 9, 13, 18, 19	
B_{14}^{SMSC}	7, 9, 14, 15, 16, 17	1, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	7, 9, 14, 15, 16, 17	III
B_{15}^{SMSC}	7, 9, 14, 15, 16, 17	1, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	7, 9, 14, 15, 16, 17	III
B_{16}^{SMSC}	7, 9, 14, 15, 16, 17	1, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	7, 9, 14, 15, 16, 17	III
B_{17}^{SMSC}	7, 9, 14, 15, 16, 17	1, 3, 7, 9, 13, 14, 15, 16, 17, 18, 19	7, 9, 14, 15, 16, 17	III
B_{18}^{SMSC}	1, 3, 5, 6, 7, 9, 13, 14, 15, 16, 17, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_{19}^{SMSC}	1, 5, 6, 13, 14, 15, 16, 17, 19	1, 3, 7, 9, 13, 18, 19	1, 13, 19	

Table A.9
Priority level of barriers Iteration-IV

Barrier	Reachability set	Antecedent set	Intersection set	Level
B_1^{SMSC}	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18, 19	
B_3^{SMSC}	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 18	1, 3, 7, 9, 18	
B_7^{SMSC}	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_9^{SMSC}	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_{13}^{SMSC}	7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18, 19	7, 9, 13, 18, 19	IV
B_{18}^{SMSC}	1, 3, 7, 9, 13, 18, 19	1, 3, 7, 9, 13, 18	1, 3, 7, 9, 13, 18	
B_{19}^{SMSC}	1, 13, 19	1, 3, 7, 9, 13, 18, 19	1, 13, 19	IV

Table A.10
Priority level of barriers Iteration-V

Barrier	Reachability set	Antecedent set	Intersection set	Level
B_1^{SMSC}	1, 3, 7, 9, 18	1, 3, 7, 9, 18	1, 3, 7, 9, 18	V
B_3^{SMSC}	1, 3, 7, 9, 18	1, 3, 7, 9, 18	1, 3, 7, 9, 18	V
B_7^{SMSC}	1, 3, 7, 9, 18	1, 3, 7, 9, 18	1, 3, 7, 9, 18	V
B_9^{SMSC}	1, 3, 7, 9, 18	1, 3, 7, 9, 18	1, 3, 7, 9, 18	V
B_{18}^{SMSC}	1, 3, 7, 9, 18	1, 3, 7, 9, 18	1, 3, 7, 9, 18	V

References

Abdulrahman, M.D., Gunasekaran, A., Subramanian, N., 2014. Critical barriers in implementing reverse logistics in the Chinese manufacturing sectors. Int. J. Prod. Econ. 147, 460–471.

Ahmadi, H.B., Kusi-Sarpong, S., Rezaei, J., 2017. Assessing the social sustainability of supply chains using best worst method. Resour. Conserv. Recycl. 126, 99–106.

Ahmed, W., Ashraf, M.S., Khan, S.A., Kusi-Sarpong, S., Arhin, F.K., Kusi-Sarpong, H., Najmi, A., 2020. Analyzing the impact of environmental collaboration among supply chain stakeholders on a firm's sustainable performance. Operations Management Research 13, 4–21.

Alam, A.J., Ahmed, S., Asadullah, S., 2018. Supplier collaboration for new product development in automobile industry. J. Manag. 5 (4).

Ali, E., 2021. The impacts of Triple-A supply chain on supply chain performance in Ethiopian textile share company. Int. J. Finan. Account. Manage. 3 (3), 245–258.

Alora, A., Barua, M.K., 2019. Barrier analysis of supply chain finance adoption in manufacturing companies. Benchmark Int. J. 26 (7), 2122–2145.

Butt, A.S., Shah, S.H.H., Sheikh, A.Z., 2020. Is guanxi important in a buyer-supplier relationship? Case of Chinese logistics industry. J. Asia Bus. Stud. 14 (1), 1–14.

Baah, C., Acquah, I.S.K., Ofori, D., 2021. Exploring the influence of supply chain collaboration on supply chain visibility, stakeholder trust, environmental and financial performances: a partial least square approach. Benchmark Int. J. 29 (1), 172–193.

Badri Ahmadi, H., Lo, H.W., Gupta, H., Kusi-Sarpong, S., Liou, J.J., 2022. Analyzing interrelationships among environmental sustainability innovation factors. Clean Technol. Environ. Policy 1–17.

Chen, L., Zhao, X., Tang, O., Price, L., Zhang, S., Zhu, W., 2017. Supply chain collaboration for sustainability: a literature review and future research agenda. Int. J. Prod. Econ. 194, 73–87.

Chen, P.K., Ye, Y., 2020. Implementation strategy of environmental management systems in supply chains. Prod. Plann. Control 1–12.

Chi, M., Huang, R., George, J.F., 2020. Collaboration in demand-driven supply chain: Based on a perspective of governance and IT-business strategic alignment. Int. J. Inf. Manag. 52, 102062.

Duong, L.N.K., Chong, J., 2020. Supply chain collaboration in the presence of disruptions: a literature review. Int. J. Prod. Res. 58 (11), 3488–3507.

Fan, Y., Stevenson, M., 2018. Reading on and between the lines: risk identification in collaborative and adversarial buyer–supplier relationships. Supply Chain Manag.: Int. J. 23 (4), 351–376.

Feng, T., Jiang, Y., Xu, D., 2020. The dual-process between green supplier collaboration and firm performance: a behavioral perspective. J. Clean. Prod. 260, 121073.

Geng, R., Mansouri, A., Aktas, E., Yen, D.A., 2020. An empirical study of green supplier collaboration in the Chinese manufacturing sector: the double-edged sword effect of guanxi. Supply Chain Manag.: Int. J. 25 (3), 359–373.

Govindan, K., Aditi, Dhingra Darbari, J., Kaul, A., Jha, P.C., 2021. Structural model for analysis of key performance indicators for sustainable manufacturer–supplier collaboration: a grey-decision-making trial and evaluation laboratory-based approach. Bus. Strat. Environ. 30 (4), 1702–1722.

Govindan, K., Kaliyan, M., Kannan, D., Haq, A.N., 2014. Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. Int. J. Prod. Econ. 147, 555–568.

Gutierrez, A., Kothari, A., Mazuera, C., Schoenherr, T., 2020. Taking Supplier Collaboration to the Next Level. McKinsey & Company. July, 7.

Hidayat, R., Hudha, K., Akhmad, S., 2015. Effects of supplier-manufacturer relationships on supply-chain performance of manufacturing industries in Indonesia. Makara Journal of Technology 19 (2), 51–58.
Howard, M., Vidgen, R., Powell, P., 2003. Overcoming stakeholder barriers in the automotive industry: building to order with extra-organizational systems. J. Inf. Technol. 18 (1), 27–43.
Huq, F.A., Chowdhury, I.N., Klassen, R.D., 2016. Social management capabilities of multinational buying firms and their emerging market suppliers: an exploratory study of the clothing industry. J. Oper. Manag. 46, 19–37.
Jääskeläinen, A., Thitz, O., 2018. Prerequisites for performance measurement supporting purchaser-supplier collaboration. Benchmark Int 25 (1), 120–137.
Jena, R.K., Dwivedi, Y., 2021. Prioritizing the barriers to tourism growth in rural India: an integrated multi-criteria decision making (MCDM) approach. J. Tourism 9 (3), 393–416.
Jimenez-Jimenez, D., Martínez-Costa, M., Rodriguez, C.S., 2018. The mediating role of supply chain collaboration on the relationship between information technology and innovation. J. Knowl. 23 (3), 548–567.
JS, N., Chilkapure, A., Pillai, V.M., 2019. Literature review on supply chain collaboration: comparison of various collaborative techniques. Journal of Advances in Management Research 16 (4), 537–562.
Kang, H., Jung, S.Y., Lee, H., 2020. The impact of Green Credit Policy on manufacturers' efforts to reduce suppliers' pollution. J. Clean. Prod. 248, 119271.
Kannan, D., Gholipour, P., Bai, C., 2023. Smart manufacturing as a strategic tool to mitigate sustainable manufacturing challenges: a case approach. Ann. Oper. Res. https://doi.org/10.1007/s10479-023-05472-6.
Kannan, D., Khademolqorani, S., Janatyan, N., Alavi, S., 2024. Smart waste management 4.0: The transition from a systematic review to an integrated framework. Waste Manag. 174, 1–14.
Kannan, D., Moazzeni, S., Mostafayi Darmian, S., Afrasiabi, A., 2021. A hybrid approach based on MCDM methods and Monte Carlo simulation for sustainable evaluation of potential solar sites in east of Iran. J. Clean. Prod. 279, 122368.
Kannan, D., Solanki, R., Kaul, A., Jha, P.C., 2022. Barrier analysis for carbon regulatory environmental policies implementation in manufacturing supply chains to achieve zero carbon. J. Clean. Prod. 358, 131910.
Khurshid, A., Muzaffar, A., Bhutta, M.K.S., 2021. Institutional pressures and supplier involvement: a perspective on sustainability. Operations Management Research 14 (1), 123–137.
Kim, B., Sim, J.E., 2016. Supply chain coordination and consumer awareness for pollution reduction. Sustainability 8 (4), 365.
Knoppen, D., Sáenz, M.J., 2015. Purchasing: can we bridge the gap between strategy and daily reality? Bus. Horiz. 58 (1), 123–133.
Kumar, V., Vrat, P., Shankar, R., 2021. Prioritization of strategies to overcome the barriers in Industry 4.0: a hybrid MCDM approach. Opsearch 58 (3), 711–750.
Lascelles, D.M., Dale, B.G., 1989. The buyer-supplier relationship in total quality management. J. Purch. Mater. Manag. 25 (2), 10–19.
Liu, F.H., Tsou, H.T., Chen, L.J., 2013. The impact of OEM supplier initiatives on buyer competence development: the moderating roles of collaborative relationship and competitive environment. Asia Pac. J. Manag. 30 (4), 1285–1303.
Liu, G., Fan, S., Tu, Y., Wang, G., 2021. Innovative supplier selection from collaboration perspective with a hybrid MCDM model: a case study based on NEVs manufacturer. Symmetry 13 (1), 143.
Lo, H.W., Chang, D.S., Huang, L.T., 2022. Sustainable strategic alliance partner selection using a neutrosophic-based decision-making model: a case study in passive component manufacturing. Complexity 2022.
Lozano, R., Barreiro-Gen, M., Zafar, A., 2021. Collaboration for organizational sustainability limits to growth: developing a factors, benefits, and challenges framework. Sustain. Dev. 29 (4), 728–737.
Maestrini, V., Martinez, V., Neely, A., Luzzini, D., Caniato, F., Maccarrone, P., 2018. The relationship regulator: a buyer-supplier collaborative performance measurement system. Int. J. Oper. Prod. 38 (11), 2022–2039.
Moon, J., Tikoo, S., 2003. Determinants of supplier willingness to invest in supporting a manufacturer's line. J. Market. Channel 11 (1), 53–64.
Moradlou, H., Roscoe, S., Ghadge, A., 2022. Buyer–supplier collaboration during emerging technology development. Prod. Plann. Control 33 (2–3), 159–174.
Oh, J., Rhee, S.K., 2008. The influence of supplier capabilities and technology uncertainty on manufacturer-supplier collaboration: a study of the Korean automotive industry. Int. J. Oper. Prod. 28 (6), 490–517.
Patrucco, A.S., Luzzini, D., Ronchi, S., 2017. Achieving innovation through supplier collaboration: the role of the purchasing interface. Bus. Process Manag. 23 (6), 1270–1289.
Rajesh, R., 2017. Technological capabilities and supply chain resilience of firms: a relational analysis using Total Interpretive Structural Modeling (TISM). Technol. Forecast. Soc. Change 118, 161–169.
Ramesh, A., Banwet, D.K., Shankar, R., 2010. Modeling the barriers of supply chain collaboration. J. Model. 5 (2), 176–193.
Ryu, S., Min, S., Zushi, N., 2008. The moderating role of trust in manufacturer-supplier relationships. J. Bus. Ind. 23 (1), 48–58.
Shalique, M.S., Padhi, S.S., Jayaram, J., Pati, R.K., 2021. Adoption of symbolic versus substantive sustainability practices by lower-tier suppliers: a behavioural view. Int. J. Prod. Res. 1–28.
Sharma, S.K., Singh, R., Matai, R., 2018. Force Field Analysis of Indian Automotive Strategic Sourcing Risk Management Enablers and Barriers. Measuring Business Excellence.
Sikombe, S., Phiri, M.A., 2019. Exploring tacit knowledge transfer and innovation capabilities within the buyer–supplier collaboration: a literature review. Cogent Business & Management 6 (1), 1683130.
Skjoett-Larsen, T., Thernøe, C., Andresen, C., 2003. Supply chain collaboration: theoretical perspectives and empirical evidence. Int. J. Phys. Distrib. Logist. 33 (6), 531–549.
Tarigan, Z.J.H., Tanuwijaya, N.C., Siagian, H., 2020. Does Top Management Attentiveness Affect Green Performance through Green Purchasing and Supplier Collaboration. Doctoral dissertation, Petra Christian University.
Theißen, S., Spinler, S., 2014. Strategic analysis of manufacturer-supplier partnerships: an ANP model for collaborative CO2 reduction management. Eur. J. Oper. Res. 233 (2), 383–397.
Ukko, J., Saunila, M., Nasiri, M., Rantala, T., 2022. The importance of sustainability engagement in small businesses supplier collaboration. Sustain. Dev. 30 (1), 1–9.
Vachon, S., Klassen, R.D., 2008. Environmental management and manufacturing performance: the role of collaboration in the supply chain. Int. J. Prod. Econ. 111 (2), 299–315.
Wagner, S.M., 2003. Intensity and managerial scope of supplier integration. J. Supply Chain Manag. 39 (3), 4–15.
Wlazlak, P., Säfsten, K., Hilletofth, P., 2019. Original equipment manufacturer (OEM)-supplier integration to prepare for production ramp-up. J. Manuf. Technol. Manag. 30 (2), 506–530.
Wong, C.W., Lai, K.H., Shang, K.C., Lu, C.S., Leung, T.K.P., 2012. Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance. Int. J. Prod. Econ. 140 (1), 283–294.
Wong, C.Y., Wong, C.W., Boon-Itt, S., 2015. Integrating environmental management into supply chains: a systematic literature review and theoretical framework. Int. J. Phys. Distrib. Logist. Manag. 45 (1/2), 43–68.
Xu, S., Nupur, R., Kannan, D., Sharma, R., Sharma, P., Kumar, S., Bai, C., 2023. An integrated fuzzy MCDM approach for manufacturing process improvement in MSMEs. Annal. Oper. Res. 322 (2), 1037–1073.
Yunus, E.N., Kurniawan, T., 2015. Revealing unsuccessful collaboration: a case of buyer-supplier relationship in the pharmaceutical industry. Supply Chain Forum Int. J. 16 (2), 14–28. Taylor & Francis.
Zurich, 2022. Rethinking supply chains for an uncertain world. Global risks. April 28). https://www.zurich.com/en/knowledge/topics/global-risks/rethinking-supply-chains-for-an-uncertain-world.