Proceedings of the 8th IEOM Bangladesh International Conference on Industrial Engineering and Operations Management, Dhaka, Bangladesh, December 20-21, 2025

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/BA08.20250210
Published: December 20, 2025

Identifying, Ranking, and Analyzing Interrelationships Among Barriers to Sustainable Perishable Supply Chains

Nur Md Alif Ul Islam
Department of Industrial and Production Engineering
Dhaka University of Engineering & Technology
Gazipur, Bangladesh
alif@duet.ac.bd

Md Abdullah Mia
Department of Strategic Business Development
University of Vaasa
Vaasa, Finland
mdmia@uwasa.fi

Mohammad Rakibul Hasan Chowdhury
Department of Industrial Management
University of Vaasa
Vaasa, Finland
chowdhury.rakibul15@gmail.com

Omer Tahsin
Department of Industrial and Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh
tahsin17buetipe@gmail.com

Abstract

This study aims to create and validate a model to identify the barriers to achieving sustainability in the supply chain of perishable items from the perspective of Bangladesh. The barriers were identified through a systematic review of the literature and input from experts. Then, the Stepwise Weight Assessment Ratio Analysis (SWARA) method was applied to prioritize the key barriers, followed by Interpretive Structural Modeling (ISM) to establish the relationships among those barriers. We have identified 9 key barriers to achieving sustainability in the supply chain of perishable items in this study. This analysis of data is based on the fruits business of a renowned company, so the opinions can be biased in some cases. A large amount of small business unit data was excluded. Consequently, this can be implemented on a large-scale business group rather than a small-scale business of perishable items. Decision-makers will get the advantage of this model as well as researchers and practitioners, to understand the probable barriers to achieving sustainability and adoption of Industry 4.0 in the business of perishable items. The prioritization of barriers will also assist in allocating available resources properly. This research is an original contribution of key barriers to the sustainable supply chain in the Bangladeshi business of perishable items using SWARA and the combined ISM-MICMAC approach.

Keywords
Stepwise Weight Assessment Ratio Analysis (SWARA), Interpretive Structural Modeling (ISM), Sustainability, Perishable Items Supply Chain.

1. Introduction
As described by the World Commission on Environment and Development, sustainable development refers to meeting the needs of today without jeopardizing the capacity of future generations to satisfy their own requirements (Hariembrundtland, 1985). Sustainable development is a challenge on a worldwide scale for companies spanning all sectors and disciplines (Jansen, 2003). Organizations all over the world are making significant efforts to make less of an environmental footprint, but are facing challenges in achieving this goal without effectively balancing the needs of society, environment, and economics (Fransoo et al., 2014). Food supply chains (FSCs) are even more challenging to sustain. With food waste and poor quality becoming more evident, sustainable supply chain management in the case of perishable food items is necessary, considering the number of populace in the globalized world, we find ourselves with a population projection of 9 billion by 2050 (Parfitt et al., 2010).

As demand for perishable goods has greatly increased in recent years, buyers have concurrently become more demanding in their expectations about the freshness of such products (Fortin et al., 2009). Perishable items such as vegetables, fruit, and milk are prone to degradation soon after they are produced. A product is considered perishable if it meets any of the following conditions: 1) the quality or quantity of the product significantly declines, 2) a decrease in its functioning has serious repercussions, or 3) the worth of it diminishes as time passes by (Amorim et al., 2013). Industrially perishable food products, hereafter referred to as PFPs, including fruits and vegetables, represent about 70 percent of the total food waste (Gardas et al., 2019). Approximately 15% of perishable goods in the United States spoil during transit and sales annually (Ferguson & Ketzenberg, 2006). Due to advantageous climatic circumstances, Bangladesh is a prominent producer of vegetables and fruits in South Asia. Nevertheless, a substantial quantity of these commodities was documented as being wasted (Bhuiyan et al., 2012). Annually, families in Bangladesh waste around 10.62 million tons of food (Sarker et al., 2022).

The key objective of this research is to find the most significant barriers to establishing a sustainable supply chain for perishable food items in Bangladesh. This will be done using a multi-criteria decision-making (MCDM) process. The aim is to identify and eliminate those crucial barriers to improve the efficiency of perishable goods chains and achieve sustainability and global food security.

The organization of this work follows the subsequent sequence. Section 2 presents a complete literature review concerning the underlying factors and concepts of perishable goods' supply chain management. In the next section, we discuss the framework of our research. In section 4, an overview of the results and their interpretations is provided; in section 5, we conclude and present future work.

2. Literature Review
This part of the paper identifies and analyzes the literature regarding sustainable supply chain management (SSCM), the challenges hindering the adoption of sustainability, from the perspective of perishables, and the industries relevant to this discussion.

2.1 SSCM and Perishable Items
Significant efforts have been made through various research to make the supply chain for perishable goods sustainable. In today's challenging environment, firms of perishable item face significant problems in meeting consumer demand. Customers today seek a good product at the best price, as cheap as possible, as fast as possible (Singh et al., 2019). The constant change in the quality of products at each stage makes the supply chain of perishable items more unique than most other products (Bloemhof & Soysal, 2017). This nature demands that the characteristics of market, product, and manufacturing processes simultaneously to be monitored (Romsdal et al., 2011).

As supply networks grow increasingly interconnected and interdependent, the firm's sensitivity to risks and obstacles rises from both its operations and the actions of its supply chain collaborators (Anastasiadis & Poole, 2015), (Wang et al., 2016), (Annosi et al., 2021). Disruptions to the flow of material or information can hurt a firm's overall performance (Wagner & Bode, 2008). Lack of credibility of information is a major concern (Ramesh et al., 2010), (Burgess et al., 2023).

The unpredictability of perishable goods might also potentially impact the structure and functioning of the supply chain (Abbas et al., 2023). In several cases, researchers have addressed the significance of the perishability factor of agro products in designing the supply chain. Researchers have highlighted the importance of effectively utilizing financial resources in key areas of the perishable supply chain, including logistics, warehouse facilities, and stock control (Liu et al., 2021), (Yakavenka et al., 2020). However, it's noted that this efficient operation comes with significant initial investment costs and environmental concerns related to carbon emissions (Kumar et al., 2012).
Unwillingness to facilitate training and technical education hinders the adoption of new technologies (Annosi et al., 2021), (Ramesh et al., 2010). In the case of adopting a circular economy, limited technical skills of people are identified as a barrier (Farooque et al., 2019). Dynamics of supply chain operations and strategies are influenced by external factors as well. These include pressures from consumers and industry stakeholders, community expectations, regulatory mandates at the state and international levels, as well as demands from global governance bodies (Mzembe et al., 2016). Local laws also affect the supply chain because they may affect the norms and regulations of the organization (Kumar et al., 2020). Besides, the lack of common frameworks or applicable standards, security issues, unpredictable market prices (Kumar & Singh, 2022), conversion into digital technologies (Annosi et al., 2021), and social responsibility are also the key factors in the SSCM of perishable goods.

2.2 Barriers to the Implementation of SSCM in Perishable Items: Bangladesh Perspective

While SSCM in perishable items is a global issue, most of the research on perishable food supply chain sustainability has been done in advanced countries. However, there has been a noticeable dearth of research attention given to emerging countries. (Annosi et al., 2021) addressed barriers to reducing waste in case of perishable items' supply chain network in emerging countries. (Kumar et al., 2020) determined the challenges to the implementation of SSCM in perishable items in emerging economies. So, further investigation needs to be done specially for emerging countries like Bangladesh (Table 1).

Table 1. List of barriers to the implementation of SSCM in Perishable Items

Barriers	Description	Sources
Lack of collaborative and strategic planning (B1)	Inadequate cooperation and long-term planning lead to higher expenses. The risk in the supply chain creates pressure for better performance. This highlights the significant impact of supply chain volatility.	(Wang et al., 2016), (Annosi et al., 2021)
Insufficient expertise, technology, and information (B2)	Effective information systems are necessary for monitoring and tracing product returns and connecting them to previous sales. To accomplish effective, the growth of links necessitates the provision of information support. For a successful management of green SC, it is necessary to appropriate information flows concerning the forward and backward movement of resources.	(Annosi et al., 2021), (Ramesh et al., 2010), (Farooque et al., 2019)
Logistical and infrastructural barriers (B3)	Lack of connectivity in remote areas, shortage of power supply, and improper planning in the location of distribution centers lead to wastage in the supply chain.	(Raut et al., 2019), (Kumar et al., 2020)
Lack of government support (B4)	Smaller enterprises may be deterred by onerous regulatory requirements or taxes that consume a significant amount of time. The government's resilience towards adopting modern technologies is a substantial obstacle.	(Joshi & Visvanathan, 2019), (Kumar et al., 2020)

Limited customer acceptance and Lack of awareness (B5)	Customers are often unaware of the ethical and environmental aspects. They often strive for lower prices. In the United States, approximately 75% of customers report that reputation influences their purchasing decisions, and an additional 80% would be ready to pay extra for environmentally responsible items.	(Lamming & Hampson, 1996), (Annosi et al., 2021)
Lack of supply chain vision/ understanding (B6)	Without visibility into their supply chain, companies risk losing oversight of their supplier network. Insufficient or excessive inventory might occur at several points if there is a lack of the capability to accurately predict demand.	(Ramesh et al., 2010), (Annosi et al., 2021)
Insufficient trust between the partners within the supply chain (B7)	Collaborators of the supply chain need to share an uninterrupted flow of information to assess the risks and challenges associated with this type of volatile supply chain.	(Shareef et al., 2022), (Kumar et al., 2020)
High investment cost (B8)	IT enablement, technology progress adoption, acquiring high-quality people, motivating, and training staff for SSCM require a significant initial expenditure. Maintaining and coordinating logistics is also expensive at times.	(Ramesh et al., 2010), (Annosi et al., 2021)
Improper demand forecast (B9)	Overestimating demand results in inflated inventory levels and increased expenses. Underestimating demand results in the unavailability of desired items for numerous esteemed clients. Product wastage occurred.	(Sel et al., 2017), (Langroodi & Amiri, 2016)

3. Methodology

Aiming to achieve authenticity and reliability, this research considers both quantitative and qualitative analysis. Literature review of previous authentic research articles is considered as qualitative analysis, from which the barriers for this study are determined as shown in Table 1. Then, opinions of a total of 20 experts are collected through direct interaction and organized interviews for the quantitative analysis. In this phase, Stepwise Weight Assessment Ratio Analysis (SWARA) has been employed to analyze and rank these key barriers. Finally, the contextual relationship among these barriers has been determined through interpretive structural modeling (ISM).

3.1 SWARA

To develop a paradigmatic model that can identify and rank the key barriers, SWARA is used and obtain an in-depth explanation of this by making the model based on the previous research and the attitudes of experts (Keršulienė et al., 2010). The key phases of the SWARA method are:

Step 1: In this step, experts perform the ranking of defined barriers according to the significance they have (p_j).

Step 2: Determination of the comparative importance of the average value (s_j). It is determined how much the criterion c_j is more important than the criterion $c_j + 1$.

Step 3: Calculation of the coefficient k_j as follows (Figure 1):

$$k_i = \begin{cases} 1; & j = 1 \\ s_{j+1}; & j > 1 \end{cases} \quad (1)$$

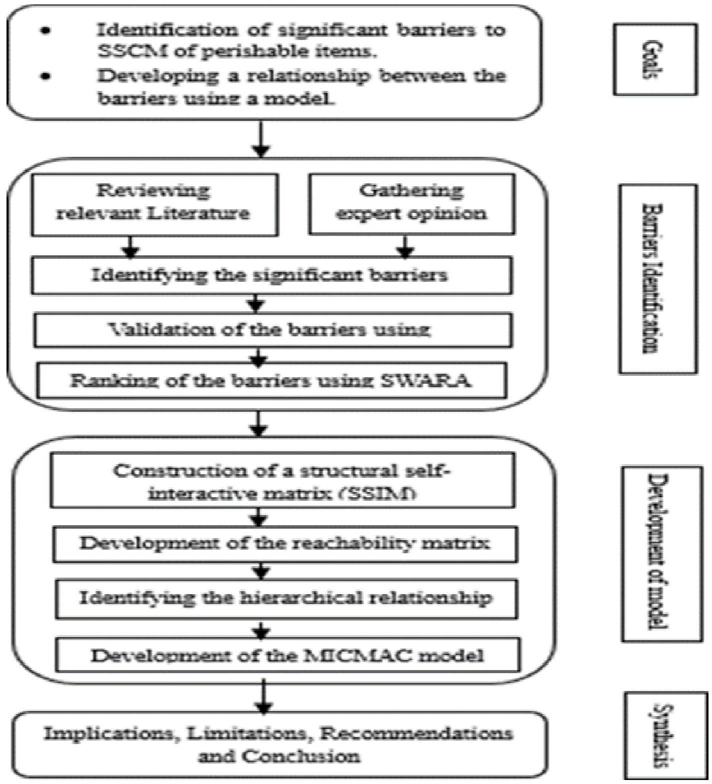

Figure 1. Methodology of research

Step 4: Determination of the recalculated weight q_j as follows:

$$q_i = \begin{cases} 1\,; j = 1 \\ \frac{q_{j-1}}{k_j}; j > 1 \end{cases} \quad (2)$$

Step 5: Calculation of the weight values of barriers with the sum that is equal to one

$$w_j = \frac{q_j - 1}{\sum_1^m q_i} \quad (3)$$

Where w_j represents the relative weight value of each barrier.

Figure 2 is sequentially presented based on the calculated weight of the barriers. sj represents the average expert ratings on each barrier.

3.2 ISM-MICMAC

To determine the interrelation among these factors ISM MICMAC methodology is used. ISM can help manage the growing number of variables that matter about a problem or an issue. Thus, some variables can be excluded while developing the ISM model, as they can profoundly affect the system. Now, an ISM-based model is constructed to categorize the barriers, utilizing MICMAC analysis for this classification.

The MICMAC approach is used to identify important factors, which are those with the highest driving power and higher dependency power (Troche-Escobar et al., 2018). The driving power and dependency power of each barrier are calculated, respectively, by summing up all the interaction possibilities contained within each row and column of the MICMAC analysis. The variables are categorized elegantly into four distinct groups based on these calculations (Kannan & Haq, 2007).

3.3 Construction of Structural Self-Intersection matrix (SSIM)

To construct the SSIM, contextual relationships among the barriers to implementing a SSCM for perishable goods were established based on insights from expert evaluations. The information gathered from 7 business specialists was deemed appropriate for the research. The opinions of the experts were gathered through direct interaction and organized interviews. In the SSIM, four symbols (as outlined in Figure 3) are used to represent the directional relationship between any two barriers, i and j.

V stands for barrier i will aid in the achievement of barrier j; A is the barrier j will help attain barrier i; X is the barrier i and j will help attain each other; and O is the barrier i and j have no relationship at all (Figure 3).

Name of the Barriers		p_j	s_j	k_j	q_j	w_j
Insufficient expertise, technology, and information	B1	0.83		1.00	1.00	0.14
Lack of supply chain vision/ understanding	B2	0.71	0.11	1.11	0.90	0.13
Improper demand forecast	B3	0.64	0.07	1.07	0.84	0.12
Insufficient trust between the partners within the supply chain	B4	0.60	0.04	1.04	0.80	0.12
Lack of collaborative and strategic planning	B5	0.57	0.03	1.03	0.78	0.11
Logistical and infrastructural barriers	B6	0.49	0.09	1.09	0.72	0.10
Limited customer acceptance and Lack of awareness	B7	0.43	0.06	1.06	0.68	0.10
High investment cost	B8	0.33	0.10	1.10	0.62	0.09
Lack of government support	B9	0.23	0.10	1.10	0.56	0.08
			0.60		6.90	

Figure 2. Result of SWARA: Ranking of the barriers

Barriers	B2	B3	B4	B5	B6	B7	B8	B9
Insufficient expertise, technology, and information (B1)	V	V	O	V	O	V	A	A
Lack of supply chain vision/ understanding (B2)		V	A	X	A	A	O	O
Improper demand forecast (B3)			O	A	A	O	O	O
Insufficient trust between the partners within the supply chain (B4)				V	O	V	O	O
Lack of collaborative and strategic planning (B5)					X	X	O	O
Logistical and infrastructural barriers (B6)						O	A	A
Limited customer acceptance and Lack of awareness (B7)							O	O
High investment cost (B8)								A
Lack of government support (B9)								X

Figure 3. Structural self-intersection matrix (SSIM)

3.4 Construction of Reachability Matrix (RM)

In this step, the SSIM is used to derive the initial reachability matrix (RM), a binary matrix, performing this to replace V, O, A, and X with 1 or 0, as shown in Figure 4.

According to the principle of transitivity, if variable U is linked to variable V, and V is linked to variable W, then U is also assumed to be linked to W. This rule is applied in the development of the Reachability Matrix (RM). The finalized RM, with transitive links clearly highlighted in red, is presented in Figure 5.

3.5 Level partition for barriers

To split the barriers into different levels, the final reachability matrix is used to identify the reachability and antecedent set for each barrier (Kannan & Haq, 2007). The reachability set for a given barrier includes the barrier itself, along with all other barriers it can potentially help address. In the final RM, this set is identified by locating all the barriers marked with a binary value of 1 in the corresponding row. The antecedent set comprises a given barrier along with all other barriers that have an influence on it. In the final RM, this set is identified by the presence of binary digit 1s in the corresponding column of the barrier. The set of intersections is made up of barriers that are shared by the reachability set and the antecedent set. A barrier is given a level in the ISM hierarchy if its intersection set and reachability set are the same, as shown in Figure 3. A barrier is abandoned to find new levels once it has been given a level. Until each barrier's level is established, this method is repeated.

3.6 Development of ISM-based model

The model for ISM-based obstacles to sustainable supply chain implementation in the Bangladeshi perishable items value chain is developed in Figure 6 from the final reachability matrix and level partition. The model of this paper shows the six-level structural relationship between the key barriers. Through a methodical framework, the model develops a suitable hierarchy of the primary obstacles in the business of perishable items.

	B1	B2	B3	B4	B5	B6	B7	B8	B9
B1	1	1	1	0	1	0	1	0	0
B2	0	1	1	0	1	0	0	0	0
B3	0	0	1	0	0	0	0	0	0
B4	0	1	0	1	1	0	1	0	0
B5	0	1	1	0	1	1	1	0	0
B6	0	1	1	0	1	1	0	0	0
B7	0	1	0	0	1	0	1	0	0
B8	1	0	0	0	0	1	0	1	0
B9	1	0	0	0	0	1	0	1	1

Figure 4. Initial reachability matrix for barriers

	B1	B2	B3	B4	B5	B6	B7	B8	B9	Driving
B1	1	1	1	0	1	1	1	0	0	6
B2	0	1	1	0	1	1	1	0	0	5
B3	0	0	1	0	0	0	0	0	0	1
B4	0	1	1	1	1	1	1	0	0	6
B5	0	1	1	0	1	1	1	0	0	5
B6	0	1	1	0	1	1	1	0	0	5
B7	0	1	1	0	1	1	1	0	0	5
B8	1	1	1	0	1	1	1	1	0	7
B9	1	1	1	0	1	1	1	1	1	8
Dependence	3	8	9	1	8	8	8	2	1	

Figure 5. Completed reachability matrix of barriers

3.7 Classification of barriers using the MICMAC analysis

The MICMAC research identified three types of obstacles and gave insights into their relevance based on their reliance power and driving power. Figure 7 depicts the driving– dependence power diagram. There is no autonomous barrier here.

4. Results

In this study, we got the ranking of the barriers with the help of SWARA. Given that supply chains are slowly becoming more complicated than what they present themselves to be, with numerous permutations of interdependent parts, it is important to know not only what the barriers are but also how they interface. For this purpose, we adopted a hybrid multi-criteria decision making (MCDM) approach, which includes SWARA, ISM, and MICMAC analyses.

Barriers	Reachability	Antecedent	Intersection	Level
B1	1,2,3,5,6,7	1,8,9	1	
B2	2,3,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	
B3	3	1,2,3,4,5,6,7,8,9	3	I
B4	2,3,4,5,6,7	4	4	
B5	2,3,5,6,7	1,2,4,5,6,7,8,9	2,3,5,6,7	
B6	2,3,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	
B7	2,3,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	
B8	1,2,3,5,6,7,8	8	8	
B9	1,2,3,5,6,7,8,9	9	9	

Barriers	Reachability	Antecedent	Intersection	Level
B1	1,2,5,6,7	1,7,8,9	1	
B2	2,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	II
B4	2,4,5,6,7	4	4	
B5	2,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	II
B6	2,5,6,7	1,2,4,5,6,7,8,9	2,5,6,7	II
B7	2,5,6,7	2,4,5,6,7,8,9	2,5,6,7	II
B8	1,2,5,6,7,8	8	8	
B9	1,2,5,6,7,8,9	9	9	

Barriers	Reachability	Antecedent	Intersection	Level
B1	1	1,8,9	1	
B4	4	4	4	III
B8	1,8	8	8	
B9	1,8,9	9	9	

Barriers	Reachability	Antecedent	Intersection	Level
B1	1	1,8,9	1	IV
B8	1,8	8	8	
B9	1,8,9	9	9	

Barriers	Reachability	Antecedent	Intersection	Level
B8	8	8	8	V
B9	8,9	9	9	

Barriers	Reachability	Antecedent	Intersection	Level
B9	9	9	9	VI

Figure 6. Iterations to find levels of barrier (1st, 2nd, 3rd, 4th, 5th, 6th iterations serially)

4.1 Barrier Prioritization Using SWARA

The Step-wise Weight Assessment Ratio Analysis (SWARA) method was employed to rank the barriers based on expert input. According to the result of SWARA analysis, the barriers are (i) Insufficient expertise, technology, and information, (ii) Lack of supply chain vision/ understanding, (iii) Improper demand forecast, (iv) Insufficient trust between the partners within the supply chain, (v) Lack of collaborative and strategic planning, (vi) Logistical and infrastructural barriers, (vii) Limited customer acceptance and Lack of awareness, (viii) High investment cost, (ix) Lack of government support.

This ranking reflects a strong emphasis on human and technological capacity as the primary concern. It provides examples of how basic knowledge gaps and limited access to technology can severely worsen a supply chain's performance. As is, the recognition of barriers such as trust, strategic alignment, and infrastructure that can undermine the efficiency and collaboration of the network was also made.

4.2 Structural Interrelations via ISM and MICMAC

After that, ISM and MICMAC analyses are done on the dataset to determine interrelation and validation. This ranking

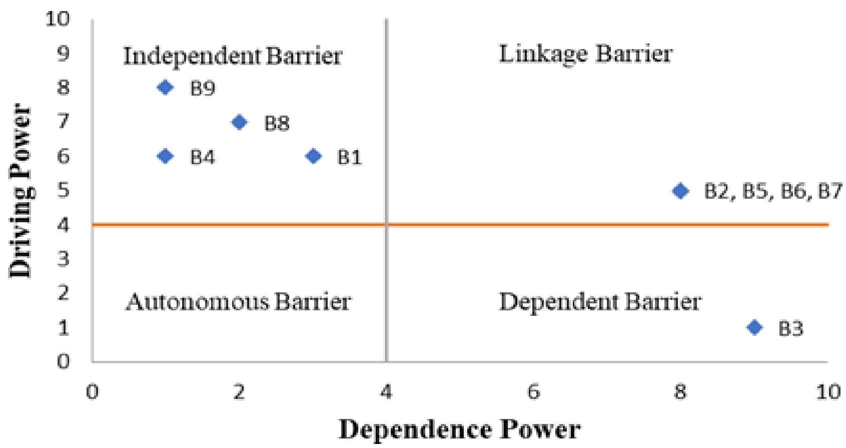

Figure 7. MICMAC analysis: Driving dependence power diagram

reflects a strong emphasis on human and technological capacity as the primary concern (Figure 7). According to MICMAC analysis, we found that Insufficient expertise, technology, and information (B1), High investment cost (B8), Insufficient trust between the partners within the supply chain (B4), and Lack of government support (B9) are independent barriers. Consequently, they are the most significant as they have a high driving power but a low dependency power.

Lack of supply chain vision/ understanding (B2), Lack of collaborative and strategic planning (B5), Logistical and infrastructural barriers (B6), and Limited customer acceptance and Lack of awareness (B7) are linkage barriers. As they are being influenced by other variables, they need dynamic multi-stakeholder strategies to counter them. Last of all, improper demand forecasting was found to be the most dependent barrier, perhaps due to broader systemic issues such as lack of trust, technology and infrastructure. It implies that unless it is addressed upstream, improving forecasting accuracy may have little effect.

5. Limitations and Future Recommendations

As the majority of participants came from the renowned business groups of Bangladesh, and the majority of them were managers, a lot of small businessmen and their scenarios were overlooked. As a result, some prejudice is to be expected. Furthermore, owing to the underlying multidimensional idea of a sustainable supply chain, certain sustainability principles may have been comprehended insufficiently or inaccurately by participants.

In the future, the opinion of middle managers and field workers needs to be incorporated. Moreover, since sustainability is intrinsically complex, the environmental and social aspects of it need to be further studied.

6. Conclusion

This study explored the critical barriers hindering the implementation of a sustainable supply chain for perishable food items in Bangladesh, an issue that has become increasingly urgent in the context of rising global food demand, widespread food waste, and environmental degradation. This research applied a comprehensive multi- criteria decision-making (MCDM) approach integrating SWARA, ISM, and MICMAC analyses to identify, prioritize, and interpret the complex network of barriers within the perishable food supply chain. Our findings revealed that the most significant obstacles include insufficient expertise, technology, and information, lack of trust among supply chain partners, high investment costs, and lack of government support. We identified these barriers as independent and high beyond any power, suggesting that preventing improvements in these areas could have far reaching improvements across the supply chain ecosystem.

This model of sustainable supply chain implementation hurdles will assist decision-makers, academics, and practitioners in anticipating potential challenges to achieving sustainability and will supplement existing academic research on supply chain management. Overall, this study contributes a structured and practical model for understanding and addressing sustainability barriers in the supply chain of perishable goods in Bangladesh. Despite its limitations, the findings offer a foundation for targeted interventions, future research, and policy formulation that aim to build more resilient, efficient, and sustainable supply chains in emerging economies.

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Biographies

Nur Md Alif Ul Islam is a Lecturer in the Department of Industrial and Production Engineering at Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh. His academic interests include operations research, production planning, supply chain optimization, and data-driven decision-making. Alongside his courses, he is highly skilled in analytical modeling, industrial problem-solving, and quantitative analysis. He is passionate about applying engineering tools to improve manufacturing efficiency and sustainability. Currently, he is exploring research directions in smart manufacturing and process improvement techniques.

Md Abdullah Mia is a Phd student in the Department of Strategic Business Development at the University of Vaasa, Finland. His academic and professional interests include business strategy, innovation management, sustainable development, and organizational competitiveness. He has been involved in various research and development activities focusing on strategic decision-making and business transformation. In addition to his academic pursuits, he is committed to understanding how emerging technologies and global trends shape modern business ecosystems. His work contributes to advancing sustainable and data-driven strategic solutions.

Mohammad Rakibul Hasan Chowdhury finished his masters in the Department of Industrial Management at the University of Vaasa, Finland. His research interests span industrial management, technology adoption, digital transformation, and organizational performance improvement. He has gained experience working in multidisciplinary academic environments and has been involved in studies related to manufacturing systems, process efficiency, and innovation practices. Beyond academics, he actively engages in exploring real-world industrial challenges and developing management frameworks to support sustainable growth. He continues to expand his expertise in modern industrial practices and business analytics.

Omer Tahsin is a BSc in the Department of Industrial and Production Engineering at Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. His academic interests include optimization, production systems, industrial simulation, and supply chain engineering. He has participated in several technical and project-based activities related to manufacturing and operations management. Alongside his coursework, he is passionate about exploring advanced computational methods and engineering tools to solve complex industrial problems. He is currently involved in research focusing on operational efficiency and process optimization.