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Analysis of Blood Supply Chain Barriers Using TOPSIS-ISM-MICMAC: A Study of the Vidarbha Region, Maharashtra, India

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Abstract

Efficient blood supply chain (BSC) management is crucial for treating sickle cell patients, particularly in the Vidarbha region of Maharashtra, India. Vidarbha is a region with a high prevalence of sickle cell disease, especially among tribal and socio-economically disadvantaged communities, making it a critical area for focused research. This study evaluates and prioritizes the barriers affecting the BSC using a multicriteria decision-making approach. Social, logistical, technological, and organizational problems are considered for grouping challenges. The research uses the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which was applied with inputs from domain experts to rank categories. The factors are rated based on how important they are in each area. Each group has a global weight. By integrating local weights for each barrier within the group into the global weight of the category, a comprehensive ranking is done for each barrier. Interpretive Structural Modelling (ISM) was also used to analyze the top ten hurdles that were linked to each other. Using the data collected, critical challenges have been uncovered. These include inadequate blood donation sites (SB2), Regulatory compliance (SB10), Demand forecasting errors (LB2), storage and shelf life (LB1), Geographic accessibility (LB9), and lack of innovation and research (TB1).Using Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis, these barriers were classified based on their driving and dependence power, highlighting their critical influence on supply chain efficiency. The study's findings can aid healthcare organizations and policymakers in formulating targeted strategies to enhance BSC and patient health..

Keywords: Blood Supply Chain, Barriers, Sickle Cell Disease, TOPSIS, ISM.

1. Introduction

Modern civilization relies on healthcare to ensure the health of its citizens and the general public. The components of blood are essential for therapy and survival [1]. They may be beneficial in treating trauma-related diseases, sickle cell anemia, and the requirement for immediate blood transfusions[2]. Patient safety and equitable access to timely medical care are significantly compromised when the blood supply chain (BSC) is unable to perform its critical functions efficiently [3], [4]. The BSC may be unable to get blood and its parts to the right places and times because of several linked problems. The issues include insufficient infrastructure, discrepancies between supply and demand, and systemic inefficiencies. There is a possibility that this might put people's lives in danger and reduce the overall reliability of medical services [5], [6]. A reliable blood bank is necessary in life-threatening scenarios where rapid access to blood is crucial for survival. In life-threatening scenarios where prompt access to blood is crucial for survival, a reliable blood bank becomes increasingly essential. In regions of India, such as the Vidarbha area, where access to medical care is constrained, the need for a reliable BSC is significantly heightened.[7] [8].

Most of the world's sickle cell disease sufferers live in sub-Saharan Africa, India, or the Middle East. India has a significant impact on the condition. It remains a primary public health concern, especially in central India, where rural and tribal populations have higher incidence rates[9]. This load is hefty in the middle region of India. Blood transfusions can make sickle cell disease patients heal and possibly save their lives. There is much uncertainty around the Vidarbha region's healthcare system due to numerous challenges. Problems include a shortage of available staff, insufficient funding for new machinery, and underused space. The BSC's effectiveness varies from other systems due to regional and economic factors. These limitations make it more difficult to obtain blood and components. As a result, some people cannot avail themselves of immediate medical facilities for critical care. Given the life-critical nature of timely blood availability and the region's vulnerability, it is imperative to understand the root causes of inefficiencies within the BSC.

This study addresses the urgent need for a robust and efficient BSC in the Vidarbha region of India. The region presents a unique case where socio-economic disparities,

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cultural attitudes, and infrastructural shortcomings converge, making it essential to examine the barriers holistically. The following key research questions guide this paper.

- What are the most significant barriers hindering the effective functioning of the BSC in the Vidarbha region of Maharashtra, India?
- How can these barriers be prioritized to guide focused policy interventions and resource allocation?
- What are the interrelationships between the most influential barriers, and how do they impact?

This study uses an integrated decision-making approach to systematically identify, analyze, and rank the key barriers in the BSC. This includes employing the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method [10].The approach includes computing weights for the four categories of obstacles, i.e., social, logistical, technical, and organizational, as well as each subfactor within these categories. The study constructs composite scores based on these weights, ranking the challenges globally. The TOPSIS approach is suitable for identifying the primary challenges impeding the BSC from running effectively and reliably since it is scientifically rigorous and objective. This analysis is followed by Interpretive Structural Modelling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis [11] to reveal their interdependencies and relative driving and dependence powers. This dual-layer evaluation helps clarify the relative influence of obstacles within each category and across the system. The findings of this study are expected to enhance understanding of the BSC issues in low-resource settings and serve as a foundation for developing resilient healthcare logistics frameworks.

This study evaluates the critical healthcare challenge in the Vidarbha region and contributes to the discourse on supply chain resilience in resource-constrained environments. By examining global and local rankings and analyzing their interrelationship, stakeholders can discern the most pressing challenges and devise tailored strategies to address them. Potential interventions in this domain include efforts to raise awareness about the necessity of blood donations, initiatives to improve logistical coordination, systems to integrate new technologies, and approaches to expedite hospital operations. The study helps with the healthcare system resilience improvement initiatives by providing vital input on critical barriers, which further helps devise a proactive strategy for dealing with comparable challenges.

To provide a logical exploration of this issue, the structure of this paper is as follows: Section 2 presents a comprehensive review of the relevant literature. Section 3 details the methodology used for data collection and analysis. Section 4 discusses the results obtained through the integrated TOPSIS-ISM-MICMAC framework. Section 5 interprets the findings and suggests practical implications. Finally, Section 6 concludes the study and outlines future research directions.

2. Literature Review:

The challenges faced by the BSC for sickle cell patients, particularly in resource-constrained settings are multifaceted. The barriers are grouped into four major categories: Social, Logistical, Technological, and Hospital barriers. The present research gives us some ideas about these problems, but the most important thing is to rank them carefully. The following is an organized Table 1 listing several problems and references for each. These four categories capture the diverse nature of challenges in BSC operations. Social barriers typically stem from community behavior, awareness, and systemic socio-economic factors. Logistical barriers refer to operational inefficiencies and infrastructure inadequacies[12]. Technological barriers indicate the absence or underutilization of innovations and systems integration. Lastly, hospital barriers relate to internal organizational issues, including interdepartmental coordination, staff training, and inventory practices[13]. Understanding and elaborating on each category provides critical insight into the nuances of BSC inefficiencies.

For instance, under social barriers, the lack of public awareness and insufficient blood donation culture (SB6 and SB7) affect donor turnout and influence donor retention (SB8). Employment limitations (SB4) may indirectly impact the ability of patients or family members to contribute to blood donation or caregiving roles. This might be especially true in physically distant places where worries about the cold chain (LB5) and the availability of blood delivery vehicles (LB6) could lead to scarcity. If planning (LB7) and forecasting (LB2) break down, there might be a severe shortage or an abundance of goods. Supply chain management, security, and communication face challenges due to technical limitations. Poor quality control measures (TB8) and disjointed IT infrastructure (TB3) are two examples of these constraints. Issues in healthcare institutions are just as crucial as in any other type of establishment. Operations may be hindered due to insufficient inventory monitoring systems (HB4) or a failure to coordinate between departments (HB10). Staff professionals' lack of training harms transfusion efficiency and safety (HB6). These issues prevent the treatment of sickle cell disease patients despite the fact that their medical demands are paramount and unique.Attari and Jami (2018) [14] and Torrado and Barbosa-Póvoa (2022)[15]investigated the substantial distribution difficulties associated with perishable commodities, emphasizing the intricacies of healthcare logistics. Research done by Özener et al. (2019) and Zahiri et al. (2015) [16], [17], underscores the significance of the BSC in addressing various medical needs. Singh et al. and Satam et al. (2021) [7], [18]assert that this makes life difficult for underprivileged communities. Identifying the sources of all BSC inefficiencies is essential before devising a remedy.

Research on BSC in the context of sickle cell disease is lacking in India. The BSC's problems in Vidarbha are caused by many interrelated issues that can take many forms. Some people are prohibited from giving blood because of their cultural or religious convictions. Others choose not to donate blood because they do not understand the seriousness of the problem. Social limitations can often be rather substantial. Supply chain disruptions, coordination challenges, and cold chain problems are some logistical challenges that could compromise blood safety during storage and transit. The absence of integrated information technology systems to track and forecast blood demand may result in technical inefficiencies like understocking or overstocking. The factors linked to the problems within the hospital and its operations are the lack of quality assurance protocols, inadequate inventory management systems, procurement delays, and scarce resources. Table 1 represents systemic problems for both qualitative analysis and quantitative prioritization, so it should be viewed as more than just a list. This forms the foundation for applying decision-making models like MCDM [19]–[21].

To analyze the barriers identified in Table 1, researchers have increasingly turned to analytical methods such as MCDM. It is an essential tool for supply chain management due to its ability to simultaneously evaluate multiple, often conflicting, criteria [30]–[40]. This competence is crucial because decision-makers face many increasing issues in modern supply chains, which are made worse by their complex and ever-changing structure. Successfully addressing these concerns requires decision-makers to consider many interconnected aspects, including supplier performance, risk, sustainability, quality, delivery time, and cost. Additional considerations include potential disruptions and long-term sustainability impacts. Traditional decision-making approaches often fail to capture the nuanced costs and benefits inherent in supply chain operations, emphasizing the importance of MCDM techniques [41], [42].

The Multicriteria Decision-Making (MCDM) paradigm is appropriate for the medical logistics business as it offers structured methods for assessing intricate trade-offs across several criteria. Methods such as AHP, TOPSIS, VIKOR, and PROMETHEE are commonly employed to substantiate decisions on supply chain strategy with empirical evidence. In the context of the BSC, MCDM enables the assessment of both quantitative and qualitative factors—such as cost, service quality, regulatory compliance, and sustainability. TOPSIS has been extensively applied to select optimal logistics partners and improve procurement, distribution, and inventory management performance. By incorporating MCDM approaches, organizations can enhance responsiveness, resilience, and environmental responsibility. Table 2 summarizes key MCDM-based studies relevant to the BSC.

Table 1. List of Barriers extracted from literature and experts' inputs

Category	Barrier Code	Barriers	Sources
C1. Social Barriers	SB1	Affordability of treatment/Cost and financial constraints	[3], [22], [23]
	SB2	Inadequate blood donation sites	
	SB3	Lack of community engagement	
	SB4	Limitations due to employment and career	
	SB5	Lack of family support	
	SB6	Public awareness and education	
	SB7	Insufficient culture of blood donation in society	
	SB8	Donor retention	
	SB9	The existence of cumbersome rules in different parts	
	SB10	Regulatory compliance	
	SB11	Cultural and religious practice	
C2. Logistical Barriers	LB1	Storage and shelf life	[24]–[26]
	LB2	Demand forecasting error (overstocking or understocking)	
	LB3	Packaging standards and handling procedures	
	LB4	Weakness in the distribution and blood supply process	
	LB5	Weakness in cold supply chain	
	LB6	Lack of proper blood-carrying vehicles	
	LB7	Logistics coordination issues among blood banks and healthcare providers	
	LB8	Inadequate supplier selection system	
	LB9	Geographic accessibility constraints	
C3. Technological Barriers	TB1	Lack of innovation and research	[27][28]
	TB2	Lack of specialized personnel in various departments	
	TB3	Lack of integrated IT system across the whole chain	
	TB4	Improper maintenance and repairs	
	TB5	Lack of easy access to the latest and most accurate tests	
	TB6	Safety and contamination risks	
	TB7	Lack of entire establishment of blood consumption management system in hospitals	
	TB8	Lack of quality assurance and control	
	TB9	Technology integration	
	TB10	Blood testing and compatibility	
C4. Hospital Barriers (Organizational)	HB1	Inaccurate organizationaldemand forecasting	[26], [29]
	HB2	Delays or inefficiencies in the ordering process	
	HB3	Inadequate storage facilities	
	HB4	Poorinventory tracking system	
	HB5	Inappropriate transfusion practices	
	HB6	Lack of education among healthcare staff	
	HB7	Inefficient processes for receiving and handling blood shipments from blood banks	
	HB8	There are no contingency plans for receiving blood during emergencies	
	HB9	No proper coordination with blood banks	
	HB10	Lack of interdepartmental coordination	

The study of MCDM methods in supply chain resilience has been explored well in the existing literature, primarily focusing on fundamental concepts and mathematical models. While previous research delves into resilience frameworks, optimization algorithms, and theoretical constructs, there remains a significant gap concerning the practical challenges and barriers in real-world BSC operations, particularly in critical sectors like the healthcare of sickle cell patients. This current study addresses this gap by focusing on the barriers to resilience in the healthcare supply chain, explicitly emphasizing the BSC.

3. Research Methodology:

The methodology employed in this study involves a systematic approach to identify, analyze, and prioritize barriers to resilience in the BSC for sickle cell patients. As depicted in Figure 1, the process is divided into three key stages. After analyzing the literature relevant to BSC, which showed many problems in healthcare logistics, five domain experts, including doctors and blood bank managers, who had significant experience, helped narrow the list of likely problems. This combination of academic and practical knowledge helped identify social, logistical, technical, and organizational obstacles. We prioritized the discovered barriers in the second stage using TOPSIS. In this case, experts judged the criteria based on how important they were, and TOPSIS was used to judge the problems based on how bad they were and how close they were to the best solution. This procedure produced rankings for both the categories and the obstacles.

Furthermore, ISM-MICMAC analysis was conducted to investigate the interrelationship among the top ten barriers ranked by TOPSIS. Finally, in the third stage, the study presents local and global rankings of barriers to derive actionable insights. The findings emphasize critical managerial implications and propose a clear way forward, including targeted interventions and strategies to address the most significant challenges. This methodology ensures a structured and robust analysis, combining expert judgment with quantitative decision-making techniques to enhance resilience in the BSC.

Table 2. Researches using MCDM in SC

Sr. No.	Paper title	Brief description	Reference
1	Prioritizing Barriers to Resilience in Blood Supply Chains: An Integrated Multicriteria Decision-Making Approach	To identify and rank the resilience obstacles in Tehran's BSC—the biggest in Iran—this study uses an integrated MCDM technique that combines FBWM, Delphi, and PROMETHEE.	[29]
2	Bloodmobile location selection for resilient blood supply chain: a novel spherical fuzzy AHP-integrated spherical fuzzy COPRAS methodology	The multicriteria decision-making (MCDM) tool for picking a site for a bloodmobile is shown in this study.	[43]
3	Developing a Risk Reduction Support System for Health System in Iran: A Case Study in Blood Supply Chain Management	This paper uses a new structural process called SSM-SNA-ISM (SSI) to find and rate supply chain risks (SCRs).	[44]
4	Supplier selection in the blood bags manufacturing industry using the TOPSIS model	In order to choose suppliers that were backed by a variety of academics, this study utilized a multicriteria decision-making (MCDM) technique. This approach is utilized when the choice is based on both subjective and objective factors.	[45]
5	Integration of Blockchain Technology and Prioritization of Deployment Barriers in the Blood Supply Chain	This study places an emphasis on blood supply hubs as a means of overcoming obstacles that may prevent the implementation of blockchain technology for supply chain management.	[27]

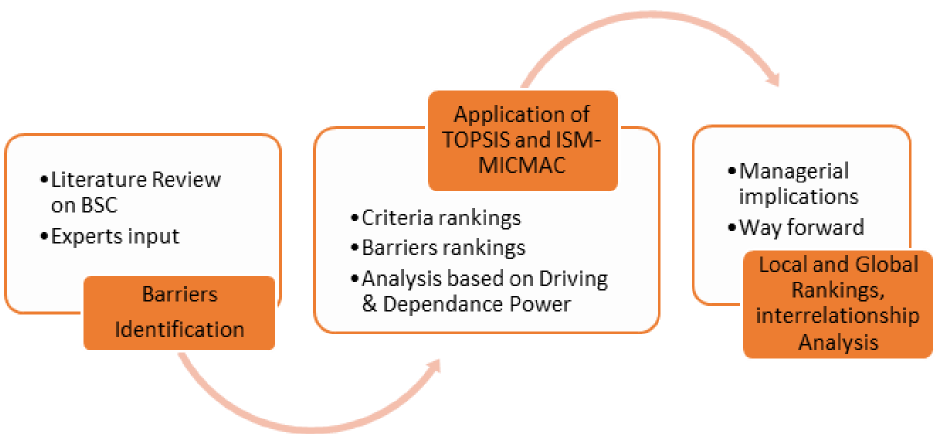

Figure 1. Methodology

4. Global and local ranking of critical barriers using TOPSIS

This part offers a methodical way to rank using the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) [21], [46], [47]. The steps involved are presented in Figure 2.

The first step is to consolidate the expert's rating table. There are 'n' numbers of criteria (field/ domain experts) n = 1, 2, 3…5 and 'm' alternatives (categories of barriers/subfactors within categories) (m = 1, 2, 3, 4). After consulting field experts' (E) importance input, the Importance matrix IR_{mn} is computed (Refer to Table 3). A grade input of one by the expert (E) suggests a modest degree of concern; a value of five denotes the most critical category in terms of barrier.

Further to input ratings, normalization is done. The distributive normalization table is constructed using the equation (i) below.

(Refer to Table 4).

$$N_{mn} = \frac{IR_{mn}}{\sqrt{\sum_{m=1}^{4} IR_{mn}^2}} \quad (1)$$

Weighted normalization of input ratings was further computed. The weight assigned to each E's rating according to their level of professional expertise is presented in Table 5.

The weighted normalization, as presented in Table 6, is computed by equation (ii).

$$Wn_{mn} = N_{mn} \times W_n \quad (2)$$

Table 3. Importance rating table

	C1	C2	C3	C4
E1	4	3	1	2
E2	2	2	3	2
E3	3	4	5	4
E4	5	5	5	5
E5	4	5	4	2

Table 4. Normalization of the rating table

	C1	**C2**	**C3**	**C4**
E1	0.7303	0.5477	0.1826	0.3651
E2	0.4364	0.4364	0.6547	0.4364
E3	0.3693	0.4924	0.6155	0.4924
E4	0.5000	0.5000	0.5000	0.5000
E5	0.5121	0.6402	0.5121	0.2561

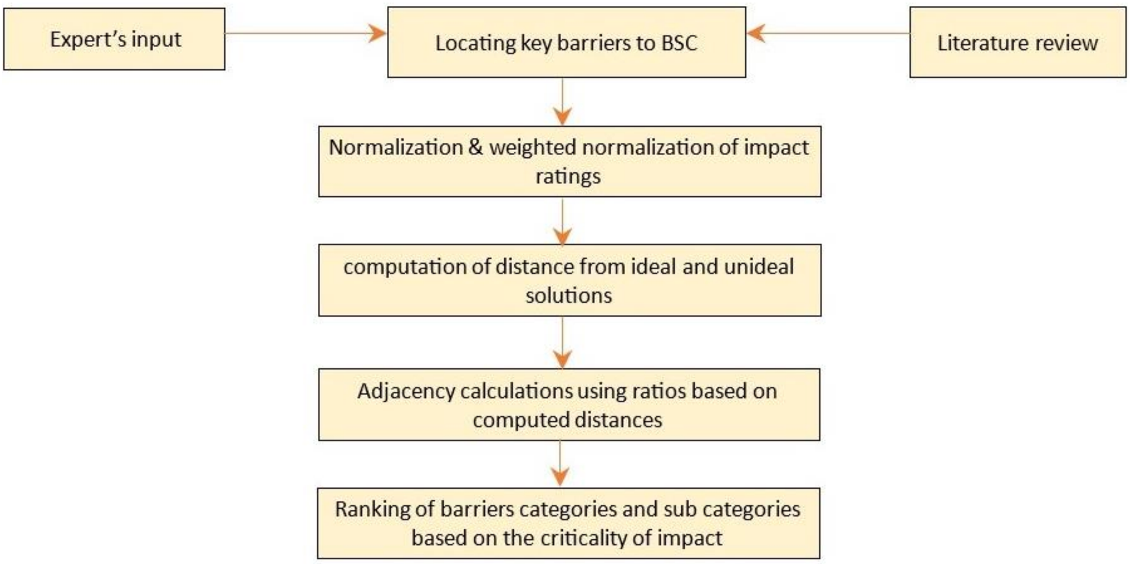

Figure 2. Flowchart for ranking using TOPSIS

Table 5. Weightage for each expert's ratings

1. Expert	**E1**	**E2**	**E3**	**E4**	**E5**	**Total**
Experience (years)	14	21	11	16	33	95
Weight W_n	0.1474	0.2211	0.1158	0.1684	0.3474	$\sum_{n=1}^{5} W_n = 1$

Table 6. Weighted Normalization of Impact Ratings

	C1	C2	C3	C4
E1	0.1076	0.0807	0.0269	0.0538
E2	0.0965	0.0965	0.1447	0.0965
E3	0.0428	0.0570	0.0713	0.0570
E4	0.0842	0.0842	0.0842	0.0842
E5	0.1779	0.2224	0.1779	0.0890

The distance between ideal and non-ideal solutions was calculated as the next step in this analysis. The ideal solution was fixed for each expert (Wn_1^{max}, Wn_2^{max}, Wn_3^{max},……Wn_5^{max}) is an optimal solution that must be established (as indicated in Table 7) by choosing the expert with the highest weighted impact rating, which is calculated using equation (iii).

$$IS_n = Wn_n^{max} = \underset{m=1,2,3,4}{\text{Max}} (Wn_{mn}) \quad (3)$$

Table 7. Ideal solution for each criterion

Expert	IS_n
E 1	0.1076
E 2	0.1447
E 3	0.0713
E 4	0.0842
E 5	0.2224

Further, as per the definition of the unideal solution, an unideal solution is produced by picking a minimal weighted impact rating for each criterion (Wn_1^{min}, Wn_2^{min}, Wn_3^{min},……Wn_5^{min})using each criterion's minimal weighted impact rating as the foundation for computation using equation (iv) below. Refer to Table 8.

$$UiS_n = Wn_n^{min} = \underset{m=1,2,3,4}{\text{Min}} Wn_{mn} \quad (4)$$

Table 8. Unideal solution for each criterion

Expert	UiS_r
E 1	0.0269
E 2	0.0965
E 3	0.0428
E 4	0.0842
E 5	0.0890

Each obstacle's distance from the optimal solution (refer to Table 9) is calculated by equation (v)

$$Dist_{B_n}^{IS} = \sqrt{\sum_{n=1}^{5} (IS_n - Wn_{mn})^2} \quad (5)$$

Table 10 illustrates each obstacle's distance from the unideal solution, and it is computed using equation (vi).

$$Dist_{B_n}^{UiS} = \sqrt{\sum_{n=1}^{5} (UiS_n - Wn_{mn})^2} \quad (6)$$

Ultimately, ratios obtained from computed distances were utilized to determine proximity. The following equation (vii) was utilized to determine the proximity of each obstacle (refer to Table 11).

$$Cl_{B_n} = \frac{Dist_{B_n}^{UiS}}{Dist_{B_n}^{IS} + Dist_{B_n}^{UiS}} \quad (7)$$

Where $0 \geq Cl_{B_n} \leq 1$, and importance is more as Cl_{B_n} Approaches towards 1.

Table 9. The distance between each factor and the ideal value

	C1	C2	C3	C4	$Dist_{B_n}^{IS}$
E 1	0.00000	0.00072	0.00652	0.00290	0.0715
E 2	0.00233	0.00233	0.00000	0.00233	0.0570
E 3	0.00081	0.00020	0.00000	0.00020	0.0922
E 4	0.00000	0.00000	0.00000	0.00000	0.1524
E 5	0.00198	0.00000	0.00198	0.01780	0.0715

Table 10. The distance between each factor and the unideal point

	C1	C2	C3	C4	$Dist_{B_n}^{UiS}$
E 1	0.00652	0.00290	0.00000	0.00072	0.1201
E 2	0.00000	0.00000	0.00233	0.00000	0.1446
E 3	0.00000	0.00020	0.00081	0.00020	0.1051
E 4	0.00000	0.00000	0.00000	0.00000	0.0304
E 5	0.00791	0.01780	0.00791	0.00000	0.1201

Table 11. Utilizing ratios derived from calculated distances for closeness calculations

Category of Barrier	Description	The relative closeness of the barrier	Rank
C1	Social Barriers	0.6267	2
C2	Logistical Barriers	0.7171	1
C3	Technological Barriers	0.5329	3
C4	Hospital Barriers (Organizational)	0.1665	4

Similarly, the ranking of barriers within each category was done by employing a similar approach, as demonstrated in the above steps. Refer to Table 12 below.

Table 12. Overall ranking of barriers

Category	Barrier Code	Barriers	Local Weight	Local Rank	Global Weight	Global Rank
C1. Social Barriers	SB1	Affordability of treatment/Cost and financial constraints	0.6546	5	0.4103	9
	SB2	Inadequate blood donation sites	0.7930	1	0.4970	1
	SB3	Lack of community engagement	0.5805	6	0.3638	13
	SB4	Limitations due to employment and career	0.2842	9	0.1781	23
	SB5	Lack of family support	0.5155	7	0.3230	16
	SB6	Public awareness and education	0.2708	10	0.1697	24
	SB7	Insufficient culture of blood donation in society	0.1972	11	0.1236	27
	SB8	Donor retention	0.3429	8	0.2149	22
	SB9	The existence of cumbersome rules in different parts	0.6792	4	0.4257	8
	SB10	Regulatory compliance	0.7446	3	0.4667	3
	SB11	Cultural and religious practice	0.7529	2	0.4719	2
C2. Logistical Barriers	LB1	Storage and shelf life	0.6446	2	0.4623	5
	LB2	Demand forecasting error (overstocking or understocking)	0.6447	1	0.4623	4
	LB3	Packaging standards and handling procedures	0.5564	5	0.3990	11
	LB4	Weakness in the distribution and blood supply process	0.3719	7	0.2667	19
	LB5	Weakness in cold supply chain	0.6265	4	0.4493	7
	LB6	Lack of proper blood-carrying vehicles	0.1642	8	0.1177	29
	LB7	Logistics coordination issues among blood banks and healthcare providers	0.1179	9	0.0845	36
	LB8	Inadequate supplier selection system	0.4694	6	0.3366	15
	LB9	Geographic accessibility constraints	0.6336	3	0.4544	6
C3. Technological Barriers	TB1	Lack of innovation and research	0.7645	1	0.4074	10
	TB2	Lack of specialized personnel in various departments	0.2214	10	0.1180	28
	TB3	Lack of integrated IT system across the whole chain	0.5430	4	0.2893	17
	TB4	Improper maintenance and repairs	0.4494	7	0.2395	21
	TB5	Lack of easy access to the latest and most accurate tests	0.4712	6	0.2511	20
	TB6	Safety and contamination risks	0.2519	9	0.1342	26
	TB7	Lack of entire establishment of blood consumption management system in hospitals	0.2846	8	0.1517	25
	TB8	Lack of quality assurance and control	0.5037	5	0.2684	18
	TB9	Technology integration	0.6500	3	0.3464	14
	TB10	Blood testing and compatibility	0.7373	2	0.3929	12
C4. Hospital Barriers (Organizational)	HB1	Inaccurate organizational demand forecasting	0.6686	2	0.1113	31
	HB2	Delays or inefficiencies in the ordering process	0.5971	3	0.0994	32
	HB3	Inadequate storage facilities	0.5490	6	0.0914	35
	HB4	Poor inventory tracking system	0.5667	5	0.0943	34
	HB5	Inappropriate transfusion practices	0.4049	7	0.0674	37
	HB6	Lack of education among healthcare staff	0.1792	9	0.0298	39
	HB7	Inefficient processes for receiving and handling blood shipments from blood banks	0.1509	10	0.0251	40
	HB8	There are no contingency plans for receiving blood during emergencies	0.3816	8	0.0635	38
	HB9	No proper coordination with blood banks	0.5772	4	0.0961	33
	HB10	Lack of interdepartmental coordination	0.7063	1	0.1176	30

5. ISM MICMAC Analysis of top ten ranked barriers:

The ISM-MICMAC methodology [11], [48], [49] involves a structured process to identify relationships among barriers and classify them based on their driving and dependence power. The steps include identifying barriers through literature review coupled with expert input, developing a Structural Self-Interaction Matrix to establish contextual relationships among barriers, converting the matrix into a Reachability Matrix followed by transitivity checks, partitioning the barriers into different levels to form an Interpretive Structural Model hierarchy, and conducting MICMAC analysis to categorize the barriers into four clusters based on their influence and dependence: autonomous, dependent, linkage, and driving factors. The flow of steps involved in ISM MICMAC analysis is presented in Figure 3. This process helps in understanding the hierarchical structure and strategic prioritization of barriers.

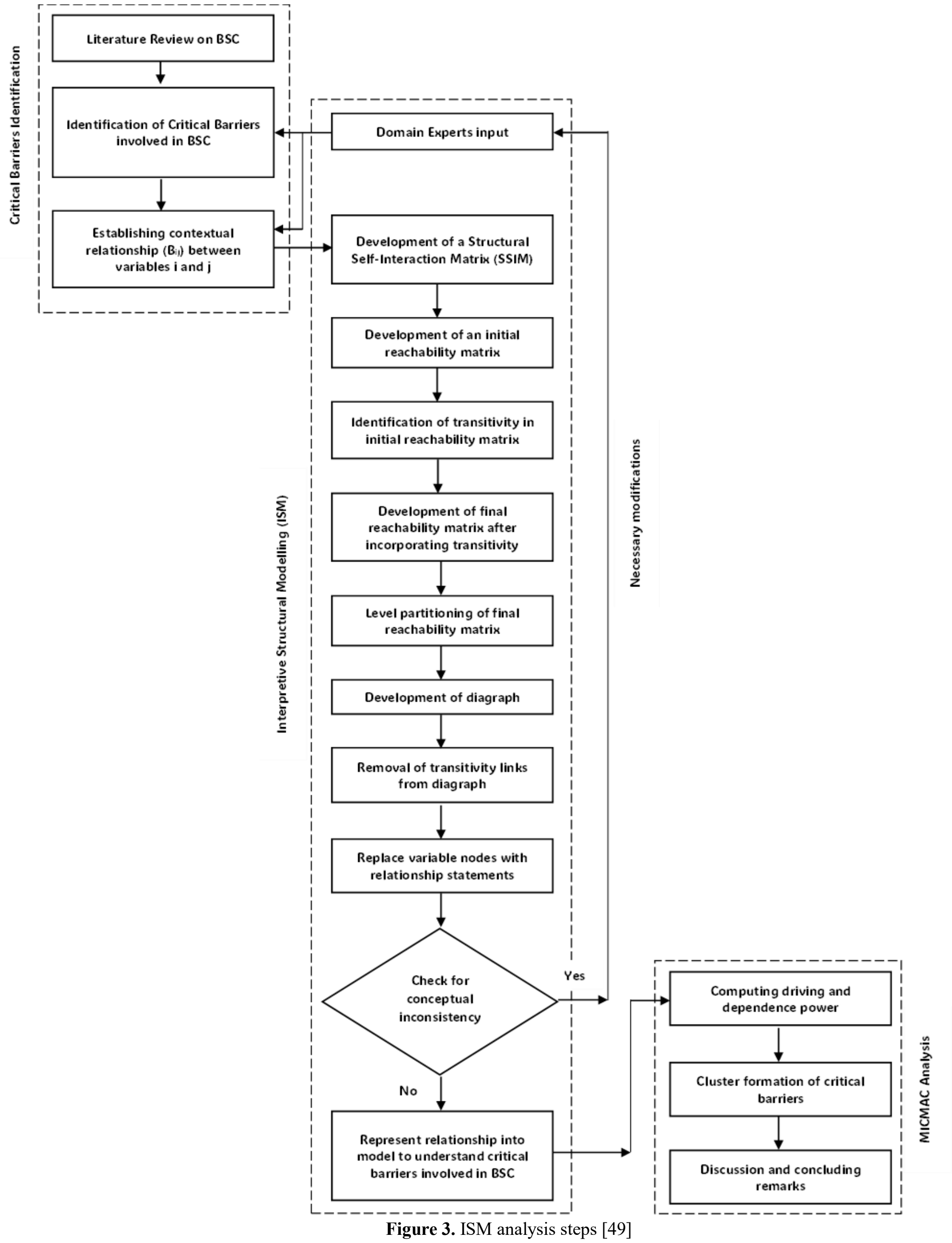

Figure 3. ISM analysis steps [49]

The first step in the ISM process involves constructing the Structural Self-Interaction Matrix (SSIM), a critical tool for capturing the pairwise relationships among the identified elements or barriers. Top ten ranked barriers were considered for further analysis. In this step, experts systematically assess the interactions between each pair of elements, indicating the direction and nature of influence using standardized symbolscommonly "V" (if element i influences element j), "A" (if element j influences element i), "X" (if elements i and j influence each other), and "O" (if there is no significant relationship). This matrix (refer to Table 13) forms the foundation for understanding the complex interdependencies in the system and guides the subsequent conversion into the reachability matrix, which ultimately helps establish the elements' hierarchical structure.

Further, the Reachability Matrix (RM)(refer to Table 14) is derived from the SSIM by converting qualitative relationships into binary values, where '1' represents a direct influence and '0' denotes no direct influence. Ultimately, the RM serves as the basis for further analysis and level partitioning in the ISM process, helping to define the hierarchical structure of the system.

The Final Reachability Matrix (FRM) incorporates transitivity by ensuring that indirect influences are captured alongside direct ones (refer to Table 15). In the FRM, if element A directly influences B and B influences C, transitivity is applied to mark that A indirectly influences C. This complete representation of direct and indirect relationships provides a robust framework for further level partitioning and hierarchical analysis in the ISM process.

Table 13. Structural Self-Interaction Matrix

Barriers	SB2	SB11	SB10	LB2	LB1	LB9	LB5	SB9	SB1	TB1
SB2	-	V	V	X	A	V	V	V	V	V
SB11		-	A	A	A	A	V	X	V	A
SB10			-	X	V	V	V	V	V	A
LB2				-	X	V	V	V	V	A
LB1					-	X	V	V	V	X
LB9						-	V	V	V	A
LB5							-	A	V	A
SB9								-	V	A
SB1									-	A
TB1										-

Table 14. Reachability Matrix

Barriers	SB2	SB11	SB10	LB2	LB1	LB9	LB5	SB9	SB1	TB1	Driving Power
SB2	1	1	1	1	0	1	1	1	1	1	9
SB11	0	1	0	0	0	0	1	1	1	0	4
SB10	0	1	1	1	1	1	1	1	1	0	8
LB2	1	1	1	1	1	1	1	1	1	0	9
LB1	1	1	0	1	1	1	1	1	1	1	9
LB9	0	1	0	0	1	1	1	1	1	0	6
LB5	0	0	0	0	0	0	1	0	1	0	2
SB9	0	1	0	0	0	0	1	1	1	0	4
SB1	0	0	0	0	0	0	0	0	1	0	1
TB1	0	1	1	1	1	1	1	1	1	1	9
Dependence Power	3	8	4	5	5	6	9	8	10	3	

Table 15. The Final Reachability Matrix

Element	Variables	SB2	SB11	SB10	LB2	LB1	LB9	LB5	SB9	SB1	TB1	Driving Power
1	SB2	1	1	1	1	1*	1	1	1	1	1	10
2	SB11	0	1	0	0	0	0	1	1	1	0	4
3	SB10	1*	1	1	1	1	1	1	1	1	1*	10
4	LB2	1	1	1	1	1	1	1	1	1	1*	10
5	LB1	1	1	1*	1	1	1	1	1	1	1	10
6	LB9	1*	1	1*	1*	1	1	1	1	1	1*	10
7	LB5	0	0	0	0	0	0	1	0	1	0	2
8	SB9	0	1	0	0	0	0	1	1	1	0	4
9	SB1	0	0	0	0	0	0	0	0	1	0	1
10	TB1	1*	1	1	1	1	1	1	1	1	1	10
	Dependence Power	6	8	6	6	6	6	9	8	10	6	

* Included transitivity

Level partitioning iterations involve systematically extracting hierarchical levels from the Final Reachability Matrix. Each iteration identifies the reachability and antecedent sets for every element, and elements whose reachability set equals their intersection set are assigned to the current level. Once these elements are removed, the process is repeated on the remaining matrix, progressively unveiling the hierarchical structure and clarifying the strategic interdependencies among the elements. Refer to tables 16 to 19 for level partitioning iterations.

Further, the conical matrix (CM) is obtained, a graphical representation derived from the level partitioning process in the ISM methodology (refer to Table 20). It organizes the elements into a conical or pyramidal structure, visually mapping the hierarchy from the most driving (at the base) to the most dependent (at the apex) factors. This matrix aids in clarifying the overall system structure and the flow of influence, thereby supporting strategic decision-making by highlighting key leverage points and their cascading effects.

The hierarchical structure in barrier modeling is created, as presented in Figure 4, to systematically organize and understand the relationships among various barriers in the BSC. Using ISM, the most critical barriers are identified and structured into levels based on their driving and dependence power. Lower-level barriers influence others, while higher-level ones are getting driven by the lower ones. The structure is created using nodes (representing barriers) and arrows (representing the directional influence from one barrier to another). This hierarchy helps decision-makers prioritize root causes and plan strategic interventions effectively.

Table 16. Level Partitioning Iteration: 1

Barriers	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
SB2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
SB11	2, 7, 8, 9	1, 2, 3, 4, 5, 6, 8, 10	2, 8	
SB10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB5	7, 9	1, 2, 3, 4, 5, 6, 7, 8, 10	7	
SB9	2, 7, 8, 9	1, 2, 3, 4, 5, 6, 8, 10	2, 8	
SB1	9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	9	1
TB1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	

Table 17. Level Partitioning Iteration 2

Barriers	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
SB2	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
SB11	2, 7, 8	1, 2, 3, 4, 5, 6, 8, 10	2, 8	
SB10	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB2	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB1	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB9	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB5	7	1, 2, 3, 4, 5, 6, 7, 8, 10	7	2
SB9	2, 7, 8	1, 2, 3, 4, 5, 6, 8, 10	2, 8	
TB1	1, 2, 3, 4, 5, 6, 7, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	

Table 18. Level Partitioning Iteration 3

Barriers	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
SB2	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
SB11	2, 8	1, 2, 3, 4, 5, 6, 8, 10	2, 8	3
SB10	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB2	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB1	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
LB9	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	
SB9	2, 8	1, 2, 3, 4, 5, 6, 8, 10	2, 8	3
TB1	1, 2, 3, 4, 5, 6, 8, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	

Table 19. Level Partitioning Iteration 4

Barriers	Reachability Set R(Mi)	Antecedent Set A(Ni)	Intersection Set R(Mi)∩A(Ni)	Level
SB2	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4
SB10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4
LB2	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4
LB1	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4
LB9	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4
TB1	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	1, 3, 4, 5, 6, 10	4

Table 20. Conical Matrix

Barriers	SB1	LB5	SB11	SB9	SB2	SB10	LB2	LB1	LB9	TB1	Driving Power	Level
SB1	1	0	0	0	0	0	0	0	0	0	**1**	**1**
LB5	1	1	0	0	0	0	0	0	0	0	**2**	**2**
SB11	1	1	1	1	0	0	0	0	0	0	**4**	**3**
SB9	1	1	1	1	0	0	0	0	0	0	**4**	**3**
SB2	1	1	1	1	1	1	1	1*	1	1	**10**	**4**
SB10	1	1	1	1	1*	1	1	1	1	1*	**10**	**4**
LB2	1	1	1	1	1	1	1	1	1	1*	**10**	**4**
LB1	1	1	1	1	1	1*	1	1	1	1	**10**	**4**
LB9	1	1	1	1	1*	1*	1*	1	1	1*	**10**	**4**
TB1	1	1	1	1	1*	1	1	1	1	1	**10**	**4**
Dependence Power	**10**	**9**	**8**	**8**	**6**	**6**	**6**	**6**	**6**	**6**		
Level	**1**	**2**	**3**	**3**	**4**	**4**	**4**	**4**	**4**	**4**		

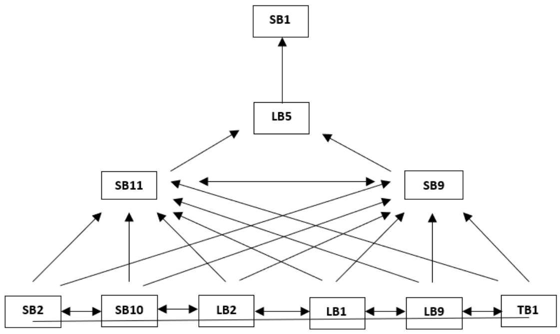

Figure 4. Barriers structure

MICMAC analysis is used to classify the identified barriers based on their driving power (influence on other barriers) and dependence power (influence received from other barriers), as depicted in Figure 5. The barriers are grouped into four categories: autonomous, dependent, linkage, and driving. The relationships identified through arrows and nodes in the hierarchical model serve as the basis for this classification. This classification aids in understanding the dynamic behavior of the system, identifying key barriers that require immediate attention, and planning targeted improvement strategies in the BSC.

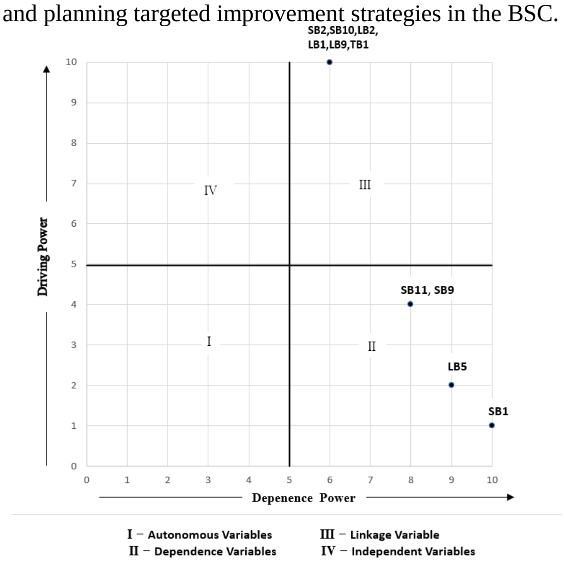

Figure 5. Barrier’s categorization

6. Results and Discussion:

The current study aimed to identify, prioritize, and analyze barriers affecting the BSC across four main categories: Social, Logistical, Technological, and Organizational. By assigning weights to each category and its respective sub-barriers, the study derived a comprehensive ranking, enabling a detailed understanding of the most critical obstacles within the system. The findings significantly impact stakeholders, such as healthcare groups and supply chain managers. The ranking analysis's findings provides a wealth of information regarding the BSC's challenges regarding resilience and efficiency. We emphasize the key categories and their corresponding sub-barriers that necessitate immediate attention.

6.1. Category Rankings

The study stresses the importance of good networks for storing, transporting, and distributing BSCs. It names Logistical Barriers (C2) as the most critical category (relative closeness = 0.7171). If we want to improve the supply chain, we need to eliminate these problems that impact the availability and quality of blood products. The second most important factor is social barriers (C1), which rank near to it (0.6267). This factor emphasizes the need for cultural knowledge, regulation adherence, and community involvement to promote blood donation and ensure fair access to blood products. Technological Barriers (C3) (relative closeness = 0.5329) stress the need for new ideas and systems that work together. Hospital Barriers (C4) (relative closeness = 0.1665) show that organizational inefficiencies continue to slow down the supply chain.

6.1.1. Logistical Barriers

The most critical logistical barriers in the blood supply chain are demand forecasting errors (LB2), storage and shelf-life limitations (LB1), and geographic accessibility challenges (LB9). Inaccurate demand forecasting (Rank 1, LB2 = 0.6447) leads to overstocking, increasing wastage due to blood's perishability, or understocking, resulting in shortages and delayed transfusions. Implementing AI-driven forecasting models and real-time demand tracking can mitigate this risk. Storage and shelf-life constraints (Rank 2, LB1 = 0.6446) pose significant challenges as blood products require strict temperature control and improper storage leads to spoilage. Strengthening inventory management systems, adopting advanced refrigeration technologies, and optimizing distribution can enhance shelf-life utilization. Geographic accessibility (Rank 3, LB9 = 0.6336) further exacerbates delays in blood transportation, particularly in remote or underserved regions. Expanding decentralized storage facilities, leveraging drone technology, and improving road infrastructure can help bridge this gap. While weaknesses in the cold supply chain, packaging standards, and supplier selection also impact logistics, addressing these top three barriers through technological advancements and strategic infrastructure development is critical for an efficient and resilient BSC.

6.1.2. Social Barriers

Based on the facts presented, the three most significant societal barriers are Inadequate blood donation sites (SB2), Cultural and religious customs (SB11), and Regulatory compliance (SB10). Cultural taboos and an absence of contribution sites are two forces discouraging people from donating blood. One way to tackle these problems is by establishing mobile blood donation units and launching community education programs. Due to the difficulties in meeting the requirements of multiple regional legislation, regulatory compliance standards stress the need for standardized policies and processes. Further, lower-ranked obstacles, such as an insufficient blood donation culture in society (SB7) and a lack of public knowledge and education (SB6), highlight the need for ongoing public engagement activities. Programs for public participation are essential in overcoming these challenges.

6.1.3. Technological Barriers

The findings emphasize the lack of innovation and research (TB1) and inadequate blood testing and compatibility measures (TB10) as key technological challenges. Developing cutting-edge blood preservation and testing technologies and integrating IT systems across the supply chain is critical [50]. The relatively low rank of obstacles, such as contamination worries (TB6), implies that frequent quality assurance is still a priority to ensure the system's dependability and trustworthiness. This is the case even though safety requirements are there.

6.1.4. Organizational Barriers

The lowest-ranked category, the organizational barriers category, draws attention to the operational inefficiencies within the company. Under this category, the most significant obstacles are a lack of interdepartmental collaboration (HB10) and inaccurate demand forecasting (HB1). These difficulties draw attention to inherent problems with organizational planning procedures and teamwork. The lack of inventory tracking systems (HB4) and emergency contingency plans (HB8) adds another element influencing these inefficiencies. Though these challenges are generally ranked lower, we must address them to create a relationship that flows naturally between hospitals and other supply chain players.

6.2. ISM-Based Structuring of Barriers in the BSC

To understand the relationships among the 10 primary challenges in the BSC, a hierarchical framework is developed utilizing ISM technique (refer to Figure 2). In categorizing barriers, ISM considers both their driving power and their reliance power. The former assesses the capacity to affect other barriers, whereas the latter evaluates the degree to which other obstacles influence a given barrier(As presented in Figure 3). Before addressing systemic inefficiencies, it is essential to ascertain their root causes, examine the interconnections among barriers, and evaluate their resultant effects. This structure may prove beneficial in formulating successful navigation route through this complex supply chain network.

6.2.1. Level 1 (Effect/Most Dependent):

The barrier SB1, Affordability of Treatment/Cost and Financial Constraints, is identified as the most dependent barrier at Level 1. As an apex dependent barrier, this factor embodies all the deficiencies and inefficiencies within the BSC. Cost-related challenges are the result of the combined impact of insufficient innovation, logistical inefficiencies, and systemic issues, which are considered upstream obstacles. A lack of suitable donation sites (SB2) and a deficient cold chain infrastructure (LB5) have a substantial impact on blood supply and expenses. Due to cultural and statutory constraints (SB10, SB11), operational independence is restricted, which further exacerbates the issues.

6.2.2. Level 2 (Intermediate Barrier):

As an intermediatory role in the ISM model hierarchy, cold supply chain inefficiency (LB5) is placed at second level. This impediment arises from an absence of innovative concepts (TB1) and challenging access owing to geographical constraints (LB9), which then affects associated elements such as expenses (SB1). Due to issues with the cold chain, the proper storage and transportation of blood is challenging, resulting in potential loss, stockouts, or increased costs.This intermediate position highlights the need for targeted interventions in cold chain infrastructure, as addressing this barrier would have ripple effects on both upstream and downstream processes.

6.2.3. Level 3 (Linkages):

The barriers SB11: Cultural and religious practices and SB9: Cumbersome rules in different parts act as linkages between the root causes and dependent effects. Cultural and religious beliefs influence donor behavior and blood donation rates, making it a significant factor in ensuring an adequate blood supply. Similarly, cumbersome rules (SB9) create inefficiencies in operations, from procurement to distribution, further complicating the supply chain. These barriers serve as critical mediators, amplifying or mitigating the effects of root causes on the dependent barriers. Their placement at Level 3 underscores the need for socio-cultural and regulatory reforms to streamline the system.

6.2.4. Level 4 (Root Causes/Most Driving):

At Level 4, the barriers with the highest driving power are identified. These include SB2: Inadequate blood donation sites, SB10: Regulatory compliance, LB2: Demand forecasting error, LB1: Storage and shelf life, LB9: Geographic accessibility, and TB1: Lack of innovation and research. These barriers are the foundational causes of inefficiencies within the blood supply chain. For example, lack of innovation (TB1) limits advancements in storage, transportation, and donor outreach technologies. Inadequate donation sites (SB2) and poor geographic accessibility (LB9) restrict the availability of blood, particularly in rural areas. Regulatory compliance (SB10) and storage issues (LB1) create logistical challenges that reduce supply chain efficiency. Addressing these root causes would significantly reduce the influence of intermediate barriers and improve affordability. These barriers have the most significant driving power, meaning systemic improvements will cascade throughout the supply chain.

7. Conclusion

Stakeholders can substantially improve the efficiency and resilience of BSC by prioritizing the resolution of high-ranking barriers, particularly those related to logistical and social categories. This research offers a concise way forward for overcoming these obstacles and promoting a more equitable and resilient BSC system. As many things are linked, it makes sense that fixing problems with logistics and technology could also help with social and medical issues. For instance, organizational training and cutting-edge forecasting tools can make it easier for hospitals to manage their activities. These tools can also help them get around legal and cultural hurdles. This viable plan stresses the importance of developing solutions that work in more than one area to improve the whole system.

This study contributes to the field by integrating MCDM techniques to rank and interpret barriers relations across multiple dimensions of the blood supply chain, particularly in the context of sickle cell disease in resource-limited settings like Vidarbha, India. Using quantitative and qualitative tools enables a nuanced understanding of critical issues and their interconnections, offering a novel perspective that combines decision analysis with structural modeling.

This being stated, there were several limitations in the study. One major limitation is the small sample size of the data, which is based largely on reviews of existing literature and the views of local experts (specific to the selected region). In addition, the model might not capture the nuances or real-time dynamics that affect BSC operations in different healthcare systems. This limits the generalisability of the findings to a worldwide scale.

Based on the study insights, several recommendations can be made for relevant stakeholders. Policymakers should prioritize investments in logistics infrastructure and staff training, while healthcare providers must work towards greater coordination between blood banks and hospitals. Community organizations should also be engaged in awareness campaigns to address social and cultural barriers to donation.

For better insights and validation from future studies, researchers should employ real-time data inputs, look at how blood logistics might benefit from emerging technologies like blockchain and AI, and compare results from other countries or regions. This study presents an opportunity to enhance the BSC's resilience in the long run by making the proposed framework more flexible and applicable to other contexts.

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