

Unlocking Circular Economy: Overcoming Roadblocks to Circular Healthcare Supply Chain in Indian Healthcare

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Abstract:

Purpose

The increased use of single-use medical devices negatively impacts the environment and promotes the linear economy. The circular economy concept in the healthcare supply chain can demote using single-use devices by reprocessing, reusing, or recycling. India is the most populous country in the world and has numerous challenges to implementing a circular economy in the healthcare supply chain. This study aims to identify and analyze the roadblocks to circular healthcare supply chains in the Indian context.

Design/methodology/approach

The contribution of the manuscript is to the healthcare supply chain in adopting a circular economy and prioritizing the roadblocks using Fuzzy FUCOM and Fuzzy Bonferroni Mean Operator. A sensitivity analysis is performed to check the robustness of the results obtained.

Findings

The finding of this study suggests that regulatory roadblocks are more critical in adopting the circular economy in the healthcare supply chain. The government is expected to formulate precise and consistent guidelines for implementing a circular economy in the healthcare supply chain. In addition, tax rebate policy should be framed for the industries taking the initiative to implement a circular economy in their system for faster implementation.

Practical implications

This study explores and prioritizes twenty secondary roadblocks categorized into five primary roadblocks. That will enhance the motivation of healthcare industries to become green and circular and contribute to the sustainability in healthcare sector. The government agencies should also take initiatives to create awareness about the circular economy among all the stakeholders.

Social Implications

This study explores and prioritizes twenty secondary roadblocks categorized into five primary roadblocks. That will enhance the motivation of healthcare industries to become green and circular and contribute to sustainability in the healthcare sector. Government agencies should also take initiatives to create awareness about the circular economy among all the stakeholders.

Originality/value

This research benefits policymakers, researchers, and industrial practitioners and is recommended based on current findings to facilitate the implementation of a circular economy in the healthcare sector.

Keywords: Healthcare supply chain, circular economy, roadblocks, Fuzzy FUCOM, Fuzzy Bonferroni Mean Operator, sensitivity analysis.

1. Introduction

The healthcare sector feels immense pressure due to several natural and artificial disasters. In the past few years, the healthcare industry has significantly increased its use of materials, energy, and resources (van Straten et al., 2021). The use of single-use medical supplies and disposable medical equipment has increased due to the health sector's growing demand and need for resources. Many of these medical products are only used once before being thrown away, significantly negatively impacting the environment. Most single-use medical devices are made of plastic, which again deteriorates the environment due to their non-biodegradable nature (Kazançoğlu et al., 2021a). Single-use disposables symbolize the linear economy, often known as "take-make-waste," in which goods are produced, consumed once, and discarded. Due to its inherent insufficiency in terms of production and consumption, this model depletes natural resources and makes an excessive amount of solid waste, greenhouse gases, and other harmful environmental emissions, all of which contribute to the destruction of the planet. Air pollution, soil and water contamination, ozone depletion, ocean acidification, biodiversity loss, and catastrophic climate change are among the repercussions that endanger human health (Macneill et al., 2020).

Organizations have been systematically implementing circular supply chain models into their operations to extend the life cycle of their products, manage waste, and develop a circular economy by encouraging customer preferences for secondary goods and products, among other goals. It suggests innovative ways to change the conventional system (consumption at the customer's end) into a circular system (Mangla et al., 2018). However, despite the emergent need for a circular supply chain in the healthcare sector, very little research has been accomplished regarding the barriers in the Indian context. (Macneill et al., 2020) have identified the barriers and enablers of the healthcare supply chain from the stakeholder's perspective but have yet to prioritize them. (Karloopia & Agrawal, 2024) have identified and modelled the barriers to design thinking implementation in healthcare sector, but circular

economy not taken into consideration. (Hoveling & Faludi, 2023) have also identified the barriers and opportunities in healthcare, but their study is limited to laparoscopic instruments. Therefore, implementing a circular healthcare supply chain (CHSC) in actual practice is much needed. Nevertheless, considering the abovementioned concerns, healthcare organizations need help applying CHSC techniques due to several obstacles.

The healthcare industry is a vital part of society that enhances people's quality of life. However, the quick development of medical technology has increased the use of medical devices, which has generated a large amount of waste. The healthcare industry can benefit from the circular economy's sustainable framework, especially when bringing new medical equipment. This strategy strongly emphasizes lowering waste, decreasing consumption of harmful/toxic materials, advancing sustainability, and developing a closed-loop resource system (Vishwakarma et al., 2022). The assessment of CHSC obstacles in the healthcare sector has been the subject of relatively few publications (Almutairi et al., 2021; Heeres et al., 2023; Kazançoğlu et al., 2021a; van Straten et al., 2021).

Consequently, it has been observed that there is a substantial research gap in the evaluation of CHSC roadblocks. Therefore, a set of appropriate solution measures must be found and ranked utilizing a decision-making process for CHSC to be adopted successfully. To overcome these difficulties, the following research questions have been framed.

RQ1: What are the main roadblocks preventing the Indian healthcare sector from adopting CHSC?

RQ2: What is the rank of identified primary and secondary roadblocks in the Healthcare industry?

The following two research objectives (RO1 and RO2) have been developed to answer the above-listed research questions. Then, describing these research objectives emphasizes the research domain and establishes limits. Thus, the main emphasis of this research is identifying the adoption of circular supply chains to determine which roadblock is the most important and evaluate each specific roadblock's effects.

RO1: To identify and ascertain primary and secondary roadblocks to implementing a circular healthcare supply chain.

RO2: To prioritize the identified primary and secondary roadblocks using fuzzy FUCOM.

This research contributes to the theory of knowledge for identifying critical roadblocks hindering the implementation of a circular healthcare supply chain. The study also prioritizes the various roadblocks by dividing them into five primary and four secondary roadblocks, each using the fuzzy FUCOM method followed by sensitive analysis using the fuzzy Bonferroni mean operator. Due to the various never-ending benefits of the circular economy, it is advantageous to implement this in the healthcare supply chain to combat the scarcity of healthcare devices. This research would be beneficial for policymakers and healthcare professionals to pinpoint the grey area of the circular healthcare supply chain.

Section 2 of the study discusses a literature review regarding barriers to the healthcare supply chain and the Fuzzy FUCOM method. Section 3 discusses the adopted research methodology. Section 4 contains an analysis of roadblocks and a calculation of their priority. Section 5 contains results and discussions. In section 6, research implications are discussed. In Section 7, the conclusion of the study, along with the limitations of the research work, is discussed.

2. Literature Review

A systematic search was performed for articles in English-speaking journals, searching for circular supply chain publications, to determine the research gap (Step 1). The bibliographic database searched is Scopus using keywords ((TITLE-ABS-KEY ({Circular Supply Chain}) AND TITLE-ABS-KEY (barriers OR roadblocks OR challenges OR hurdles OR obstacles OR impediments OR obstructions) OR TITLE-ABS-KEY({Circular Economy} AND {Supply Chain}))) The above keywords resulted in 275 articles. The scientific publications of other fields, such as physics, molecular biology, material science, and microbiology, have also been disregarded. The articles in the press were excluded to authenticate the study. To preserve the caliber of the research work, unnecessary document types such as editorials, conference reviews, brief surveys, notes, and undefined document types were eliminated. After taking all these measures, 68 articles have been considered for further analysis, further refined after reading the abstract to 40. This search identifies the research gap more clearly by confirming that no study has been published to date that focuses on roadblocks analysis of circular healthcare supply chain in the Indian context (Step 2). Roadblocks have been identified from the previous research articles.

2.1 Roadblocks of healthcare circular supply chain

Numerous studies analyzing the barriers to the healthcare supply chain have been published; however, they do not consider the circular economy while examining the Indian setting. Macneill et al. (2020) suggested that the limited use of single-use healthcare devices could

break linearity into the system by developed countries, but they have not prioritized the barriers. Almutairi et al. (2021) similarly recognized and ranked the barriers to lean implementation in developing nation healthcare systems. The study found fifteen barriers within the four topics of culture, strategy, people, and company operations. They have limited it to nine barriers after analyzing with the assistance of experts. Jain et al. (2022) have modeled the barriers of the Indian healthcare supply chain with 15 identified barriers and analyzed the interrelationships between them using ISM. This study also did not consider the circular economy concept in the supply chain. Vishwakarma et al. (2022) analyzed ten sustainable supply chain barriers in the textile sector using ISM-MICMAC and DEMATEL methods, but the circular economy was not considered. Barriers, opportunities and practices to use the circular economy for medical devices have been identified in a recent study conducted in the Netherlands, however prioritization has not been done. (Hoveling et al., 2024). In a study for the Indian healthcare supply chain that looks at the 15 obstacles to mHealth adoption in the framework of sustainable operating standards, circular economy principles have once again been ignored. (Swain et al., 2024). Based on the research mentioned above, it was found that several researchers are concentrating on the area of healthcare sector barriers while omitting to include circularity. This study aims to identify the roadblocks that stand in the way of adopting a circular healthcare supply chain in the Indian context.

Regulatory Roadblocks: The healthcare industries mainly depend on single-use medical devices, which do not promote the circular economy. Hence, the devices should be repaired, reused, remanufactured, and recycled correctly. The matter of fact is that these devices directly affect human health, so precise and consistent guidelines should be made for standardization. The medical device sector is regulated and overseen by a complicated network of institutions, where descriptions of roles and duties occasionally need to be clarified. Because organizations with competing interests have waived their regulatory responsibilities, the lack of defined mandates and bounds has facilitated the growth of single-use disposables. Confusion over the requirements for reprocessing reusable devices has arisen from a lack of precise and uniform recommendations. Many device users in this setting have turned to single-use disposables to reduce the risk of inaccuracy, citation, and liability (Macneill et al., 2020). Many nations have included CE principles in their long-term plans. In contrast to other regions, like the EU, Japan, the USA, and Russia, where it is used to establish bottom-up environmental and waste management policies, China, for example, promotes CE as a top-down political goal

(Jafarzadeh Ghouschi et al., 2022; Mangla et al., 2018). Developing countries like India have not yet taken the circular economy principle into the mainstream for sustainable development. Implementing circular practices necessitates significant financial expenditures. Thus, the need for favorable tax policies to promote CHSC has become a potential barrier to healthcare industries. Promoting CHSC ideas may be aided by tax breaks and preferential financing for waste minimization and energy conservation. Preferential tax laws, however, have only been applied selectively and occasionally in India. The absence of government encouragement and assistance (via inefficient tax laws, import and excise taxes, etc.) is typically noted as a significant barrier to adopting circular concepts (Mangla et al., 2018). The Suitable performance measurement system for implementing the circular supply chain is not standardized globally (Ayati et al., 2022; Çıkmak & Kesici, 2023; Khandelwal & Barua, 2020). As CHSC development is still in its early stages, stakeholders have challenges determining the expected return on investment for implementing CHSC practices (Agrawal et al., 2023). The direction for end-of-life product management for the recovery process is ill-defined (Lahane & Kant, 2021).

Economical Roadblocks: The circular economy implementation requires many resources related to skilled labor, new technology, and greater infrastructure, which leads to high upfront investment costs for organizations. In addition, the organizations have short-term perspectives toward financial benefits, which is also the key obstacle to implementing CHSC in the healthcare sector (Çıkmak & Kesici, 2023; Jafarzadeh Ghouschi et al., 2022; Lahane & Kant, 2021). Healthcare industries also face challenges in identifying the financial benefits of environmental investments by using eco-friendly medical supplies (Kazançoğlu et al., 2021a). Due to the high cost of recyclable materials, the cost of products increases, leading to higher sales prices of recycled products and finally affecting the sales volume (Khandelwal & Barua, 2020).

Social Roadblocks Misunderstandings and poor interpersonal communication impact the operation of the healthcare supply chain since they negatively impact both the working environment and customer satisfaction. Patients and internal customers hesitate to cooperate and trust when they receive this communication. A lack of interpersonal communication also affects the flow of information because incorrect information is disseminated across the departments and levels of the healthcare supply chain (Jain et al., 2022). The hospital's culture of reluctance to change and going with a linear approach (take-make-dispose) rather than a circular approach also hinders the use of CE in the healthcare supply chain (Almutairi et al.,

2021; Heeres et al., 2023). Many authors (Agrawal et al., 2023; Ayati et al., 2022; Kazancoglu et al., 2020; Kazançoğlu et al., 2021a; Mangla et al., 2018) have emphasized the lack of awareness of the circular economy, society itself becomes one of the roadblocks to implementing circular economy in healthcare industries. The healthcare industry is directly associated with people's lives. Hence, the safety, security, quality, and infection risks of remanufactured, recycled, and reused products have become critical roadblocks to implementing CE in the healthcare supply chain.

Technological Roadblocks: The world's societies are dealing with several related difficulties, including resource depletion, climate change, and ecological degradation. One of the two most effective ways to address these problems could be through technology transfers or new technology development. To increase the efficacy of CHSC programs, technology transfer entails moving cutting-edge technology from the originator (a developed nation) to a secondary user (a developing country). Therefore, transferring technology might be wise for a developing country like India (Mangla et al., 2018). A circular economy requires the flow of information or data to track and trace the product for reusing, remanufacturing, or recycling, hindering the process of adopting CHSC. Artificial intelligence, the Internet of Things, and blockchain technology require deep thinking, which can be implemented by highly skilled labor and training.

Management and Organisational Roadblocks: Management and organizational support play a vital role in the success of any supply chain, but if management is not supportive and there is no coordination between the organization's departments, it can seriously impact the supply chain and may cause disruption in the supply chain. To implement a circular economy in healthcare, top management needs to take the initiative as it involves many changes in organizational infrastructure and policies. The lack of established standards regarding the circular economy is one of the significant roadblocks to adopting the circular economy in the healthcare supply chain. In addition, suppliers are essential stakeholders in the supply chain while applying a circular economy. The supplier can offer refurbished products or implement sustainable and circular sourcing practices, which can help implement CHSC (Durmić et al., 2020; Ecer & Torkayesh, 2022; Mishra et al., 2022; Nasser et al., 2023). All these above roadblocks, including primary and secondary roadblocks along with their code and references, are summarised in **Table 1**.

Table 1 Various roadblocks with their sources

S. No.	Primary Roadblocks (Code)	Secondary Roadblocks	Code	Reference
1	Regulatory (RR)	Lack of precise and consistent guidelines	RR1	(Ayati et al., 2022; Hoveling & Faludi, 2023; Hoveling et al., 2024, Jafarzadeh Ghouschi et al., 2022; Macneill et al., 2020; Mahjoob et al., 2023a; Vishwakarma et al., 2022)
		Lack of favorable tax policies for promoting CSCM	RR2	(Agrawal et al., 2023; Ayati et al., 2022; Çıkmak & Kesici, 2023; Kazançoğlu et al., 2021a; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mangla et al., 2018; Shaikh et al., 2022)
		Non-existence of suitable performance measurement system	RR3	(Ayati et al., 2022; Çıkmak & Kesici, 2023; Govindan & Hasanagic, 2018; Khandelwal & Barua, 2020; Lahane & Kant, 2021)
		Unclear vision regarding product recovery in CSC	RR4	(Agrawal et al., 2023; Ayati et al., 2022; Govindan & Hasanagic, 2018; Khandelwal & Barua, 2020; Lahane & Kant, 2021)
2	Economical (ER)	High upfront investment costs	ER1	(Çıkmak & Kesici, 2023; Govindan & Hasanagic, 2018; Jafarzadeh Ghouschi et al., 2022; Kazancoglu et al., 2020, 2022; Kazançoğlu et al., 2021a; Lahane & Kant, 2021)
		Short-term perspective towards financial benefits	ER2	(Agrawal et al., 2023; Ayati et al., 2022; Karbassi Yazdi et al., 2022; Kazancoglu et al., 2020; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Macneill et al., 2020; Mangla et al., 2018; Shaikh et al., 2022)
		Lack of economical capabilities and resources on environmental investments	ER3	(Govindan & Hasanagic, 2018; Kazançoğlu et al., 2021a)
		Higher sales price of recycled products	ER4	(Agrawal et al., 2023; Ayati et al., 2022; Karbassi Yazdi et al., 2022; Khandelwal & Barua, 2020)
3	Social (SR)	Insufficient interpersonal communication with customers/patients	SR1	(Almutairi et al., 2021; Hoveling & Faludi, 2023; Jafarzadeh Ghouschi et al., 2022; Jain et al., 2022)
		Hospital culture and reluctance to change	SR2	(Almutairi et al., 2021; Heeres et al., 2023)
		Lack of CE awareness in healthcare	SR3	(Agrawal et al., 2023; Ayati et al., 2022; Çıkmak & Kesici, 2023; Govindan & Hasanagic, 2018; Jain et al., 2022; Karbassi Yazdi et al., 2022; Kazancoglu

				et al., 2020, 2022; Kazançoğlu et al., 2021a; Mangla et al., 2018)
		Safety, security, quality and infection risk of remanufactured, recycled and reused product	SR4	(Ayati et al., 2022; Çıkmak & Kesici, 2023; Hoveling et al., 2024, Kazançoğlu et al., 2021a; Lahane & Kant, 2021)
4	Technological (TR)	Lack of easily accessible data for tracking and tracing	TR1	(Agrawal et al., 2023; Ayati et al., 2022; Çıkmak & Kesici, 2023; Jafarzadeh Ghouschi et al., 2022; Kazançoğlu et al., 2021a; Lahane & Kant, 2021)
		Scarcity of skilled human resources and lack of training	TR2	(Agrawal et al., 2023; Almutairi et al., 2021; Jafarzadeh Ghouschi et al., 2022; Jain et al., 2022; Karbassi Yazdi et al., 2022; Kazancoglu et al., 2020, 2022; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mangla et al., 2018; Shaikh et al., 2022; Sonar et al., 2024)
		Lack of high-tech in reverse logistics	TR3	(Agrawal et al., 2023; Hoveling & Faludi, 2023; Jain et al., 2022; Kazancoglu et al., 2020, 2022; Khandelwal & Barua, 2020)
		Lack of implementation of new technologies in service	TR4	(Ayati et al., 2022; Heeres et al., 2023; Jafarzadeh Ghouschi et al., 2022; Jain et al., 2022; Kazancoglu et al., 2022; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mangla et al., 2018; Shaikh et al., 2022)
5	Management and Organisational (MOR)	Lack of coordination and cooperation with suppliers	MOR1	(Agrawal et al., 2023; Ayati et al., 2022; Chhabra & Singh, 2022; Heeres et al., 2023; Jain et al., 2022; Karbassi Yazdi et al., 2022; Kazancoglu et al., 2020, 2022; Kazançoğlu et al., 2021a; Lahane & Kant, 2021; Mangla et al., 2018; Shaikh et al., 2022)
		Lack of leadership commitment	MOR2	(Ayati et al., 2022; Chhabra & Singh, 2022; Çıkmak & Kesici, 2023; Jafarzadeh Ghouschi et al., 2022; Karbassi Yazdi et al., 2022; Kazancoglu et al., 2022; Kazançoğlu et al., 2021a; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mangla et al., 2018; Shaikh et al., 2022)
		Inadequate cooperation and flexibility between departments	MOR3	(Çıkmak & Kesici, 2023; Hoveling & Faludi, 2023; Jain et al., 2022; Kazançoğlu et al., 2021a; Khandelwal & Barua, 2020; Shaikh et al., 2022)

		Lack of established standards and strategies for CE activities in healthcare	MOR4	(Çıkmak & Kesici, 2023; Karbassi Yazdi et al., 2022; Kazançoğlu et al., 2021a; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mangla et al., 2018)
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The developed world has been using CHSC for a long time. However, developing countries like India require assistance to embrace CHSC due to insufficient policy norms, rules, regulations, and strategies. After a thorough analysis of the literature, it was found that many researchers focused on the identification of roadblocks in the healthcare supply chain (Almutairi et al., 2021; Heeres et al., 2023; Kazançoğlu et al., 2021a; van Straten et al., 2021). However, there is a lack of studies (Jain et al., 2022). However, no research currently considers the circular economy in the Indian healthcare supply chain. In addition, the literature that is presently accessible primarily concentrates on DEMATEL and ISM methodologies. These methods evaluate the roadblocks conventionally (Like cause-effect level partition). However, this study prioritizes obstacles to the circular healthcare supply chain using the Fuzzy FUCOM technique. This method works well for determining the various weights of the barriers. As a consequence, compared to previous procedures, it produced superior results.

3. Research Methodology

This study aims to determine the significant roadblocks to the circular economy in the healthcare supply chain and ascertain the relative significance of each roadblock in the Indian context. To fulfil these aims, first, to determine the roadblocks that made it possible to develop a questionnaire that would make data collecting more straightforward, worldwide peer-reviewed papers on the circular supply chain were considered. Second, to verify and examine these roadblocks in the Indian healthcare industries, an empirical study involving experts in the circular supply chain and healthcare professionals was carried out. Thirdly, sensitivity analysis was carried out using the Fuzzy Bonferroni Mean Operator to verify further the weights obtained from Fuzzy FUCOM. The research methodology, which gives the pictorial representation of chronology of methods used is shown in **Figure 1**.

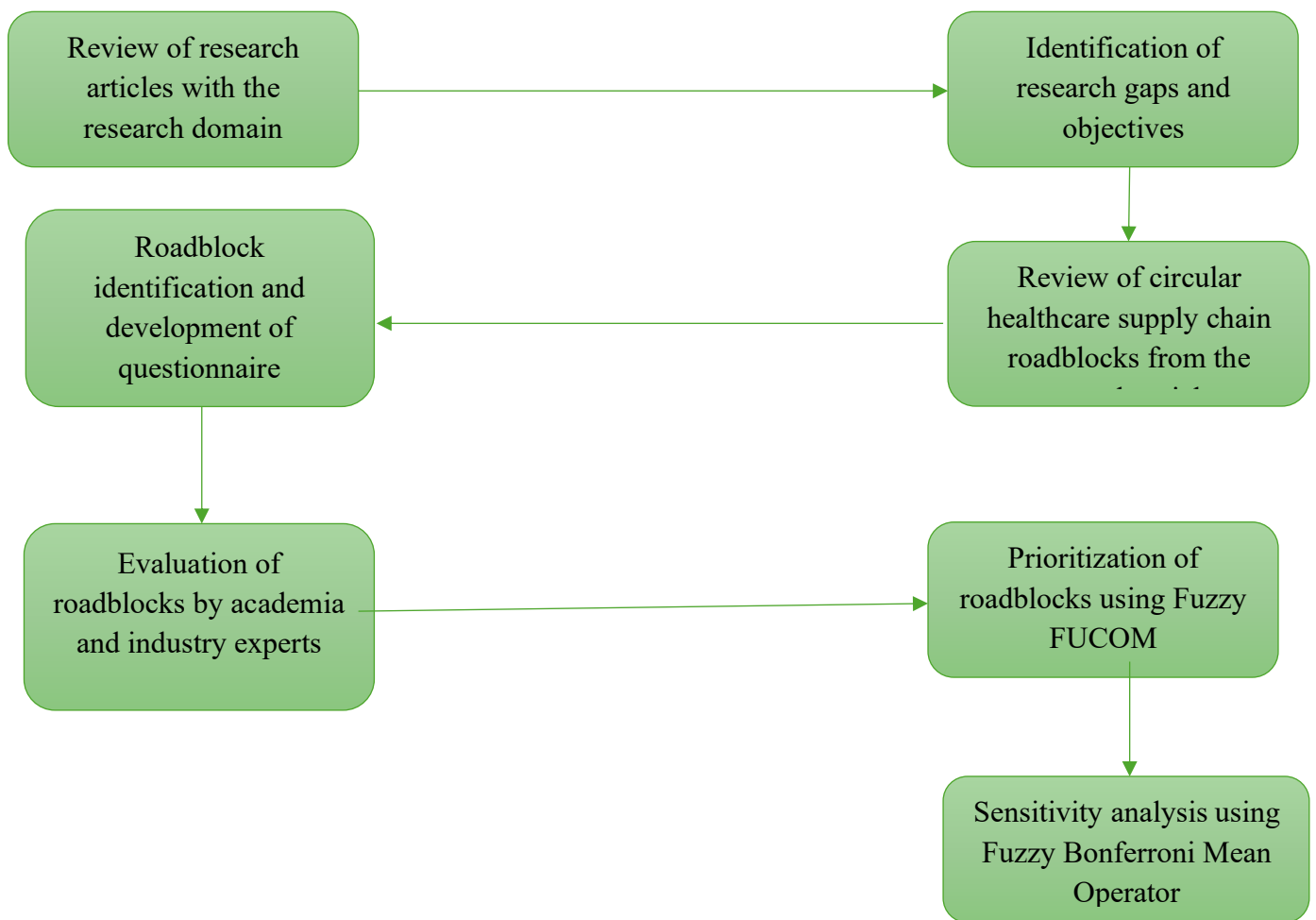


Figure 1 Research Methodology

3.1 Fuzzy FUCOM

Various MCDM techniques are available to find the factors' weight coefficients by making pairwise comparisons Viz. Analytical Hierarchy Process, Best-worst method, and FUCOM method mainly. In this study, the roadblocks of the circular healthcare supply chain are to be prioritized. For using AHP, we need to find $n(n-1)/2$ comparisons, while the best-worst method requires $(2n-3)$ comparisons. There is also a problem of inconsistent results with the AHP method. FUCOM is used in this study to overcome these difficulties. The expert opinions are based on their subjective assessment to remove the vagueness in decision-making Fuzzy- FUCOM is used in this study. (Pamučar et al., 2018) developed the FUCOM method. FUCOM is a technique that determines the weight coefficients of all the factors at

a specific hierarchy level with complete consistency. FUCOM has the following benefits compared to other popular techniques like the Analytical Hierarchy process and the Best-worst method. Fewer paired comparisons lower the possibility of inconsistency owing to judgmental bias (for FUCOM, we need $(n - 1)$ number of comparisons). Inherent characteristics to compute and assess the DFC (deviation from complete consistency) value to verify the accuracy and consistency of the outcome.

Fuzzy FUCOM

Fuzzy FUCOM is the advanced version of FUCOM, in which Fuzzy numbers are considered rather than crisp numbers to overcome vagueness in decision-making. The fuzzy FUCOM method consists of four stages, as discussed below.

Stage I: Selection of Experts and Ranking of Factors

Four experts—two medical officers from healthcare institutions, one from academia with expertise in supply chain management, and one from the healthcare industry with a connection to the manufacturing of medical devices—have been chosen to analyze the obstacles facing CHCSC, the experts profile is given in Table 2.

S. No.	Expert	Job Designation	Experience in Years	Gender	Qualification
1	#Exp 1	Medical Device Industry-Manager	15	Male	Post Graduate
2	#Exp 2	Medical Practioner (Additional Chief Health Director)	20	Male	Post Graduate
3	#Exp 3	Medical Practioner (Medical Officer)	6	Female	Post Graduate
4	#Exp 4	Professor	42	Male	Ph. D.

After the selection of experts, a Google form questionnaire is sent to all the experts. Experts compare factors and arrange them from most important to least important, as shown in **Table 2**.

Stage II: Comparison of Factors using TFN

Now, Experts rate the selected sequences using a linguistic scale for all the primary and secondary roadblocks (as given in **Table 3**) (Demir et al., 2022). More precisely, Expert compares the 1st placed factor with the 2nd placed factor and the 2nd placed factor with the 3rd placed and so on according to their importance.

Table 3 Linguistic Scale

Linguistic Variables	Symbol	Triangular Fuzzy Number (TFN)
Equally important	EI	(1,1,1)
Weakly important	WI	(2/3,1,3/2)
Fairly important	FI	(3/2,2,5/2)
Very important	VI	(5/2,3,7/2)
Absolutely important	AI	(7/2,4,9/2)

Source: (Demir et al., 2022)

Stage III: Determination of comparative and transitive weights

Now, comparative weights are to be calculated by using equations (1), (2) and (3).

$$\tilde{\varphi}_{k/(k+1)} = \frac{\tilde{\omega}_{C_{j(k+1)}}}{\tilde{\omega}_{C_{j(k)}}} = \frac{(\omega_{C_{j(k+1)}}^l, \omega_{C_{j(k+1)}}^m, \omega_{C_{j(k+1)}}^u)}{(\omega_{C_{j(k)}}^l, \omega_{C_{j(k)}}^m, \omega_{C_{j(k)}}^u)} \dots\dots\dots(1)$$

$$\tilde{\varphi} = (\tilde{\varphi}_{1/2}, \tilde{\varphi}_{2/3}, \dots, \tilde{\varphi}_{k/(k+1)}) \dots\dots\dots(2)$$

$$\frac{\tilde{\omega}_k}{\tilde{\omega}_{k+1}} = \tilde{\varphi}_{k/(k+1)} \dots\dots\dots(3)$$

After calculating the comparative weights, transitive weights can be calculated by using equation (4)

$$\frac{\tilde{\omega}_k}{\tilde{\omega}_{k+2}} = \tilde{\varphi}_{k/(k+1)} \otimes \tilde{\varphi}_{(k+1)/(k+2)} \dots\dots\dots(4)$$

Stage IV: Fomation of NLPP and calculation of optimum weights

After this, an NLPP model is formed, resulting in the factors' optimum local weights.

$$\begin{array}{c}
\text{Min } \chi \\
\text{Subjected to} \\
\left| \frac{\tilde{\omega}_k}{\tilde{\omega}_{k+1}} - \tilde{\varphi}_{k/(k+1)} \right| \leq \chi, \forall_j \text{ and } \left| \frac{\tilde{\omega}_k}{\tilde{\omega}_{k+2}} - \tilde{\varphi}_{k/(k+1)} \otimes \tilde{\varphi}_{(k+1)/(k+2)} \right| \leq \chi, \forall_j \\
\sum_{j=1}^n \tilde{\omega}_j = 1, \forall_j \\
\omega_j^l \leq \omega_j^m \leq \omega_j^u \\
\omega_j^l \geq 0, \forall_j \\
j = 1, 2, \dots, n \\
\tilde{\omega}_j = (\omega_j^l, \omega_j^m, \omega_j^u) \text{ and } \tilde{\varphi}_{k/(k+1)} = (\varphi_{k/(k+1)}^l, \varphi_{k/(k+1)}^m, \varphi_{k/(k+1)}^u)
\end{array}$$

3.2 Fuzzy Bonferroni Mean Operator

There is considerable interest in finding aggregation functions that can be utilized to model the extensive range of possible interactions between the criteria in multi-criteria situations by replacing the simple average with the Fuzzy Bonferroni mean operator, identification and association of differing importance with the arguments (Yager, 2009). The Fuzzy Bonferroni mean operator was first introduced by (Bonferroni, 1950) and discussed in detail by (Beliakov et al., 2007). In this study, we have taken four experts to prioritize the roadblocks. So, the interval fuzzy vectors obtained by Fuzzy FUCOM will be aggregated using Fuzzy Bonferroni Mean Operator, given by equation (5).

$$\tilde{\zeta}_{ij} = (\zeta_{ij}^l, \zeta_{ij}^m, \zeta_{ij}^u) = \begin{cases} \zeta_{ij}^l = \left(\frac{1}{d(d-1)} \cdot \sum_{i,j=1, i \neq j}^d (\zeta_j^l)^p \otimes (\zeta_j^l)^q \right)^{\frac{1}{p+q}} \\ \zeta_{ij}^m = \left(\frac{1}{d(d-1)} \cdot \sum_{i,j=1, i \neq j}^d (\zeta_j^m)^p \otimes (\zeta_j^m)^q \right)^{\frac{1}{p+q}} \dots\dots\dots (5) \\ \zeta_{ij}^u = \left(\frac{1}{d(d-1)} \cdot \sum_{i,j=1, i \neq j}^d (\zeta_j^u)^p \otimes (\zeta_j^u)^q \right)^{\frac{1}{p+q}} \end{cases}$$

$$\hat{\zeta}_{ij} = \frac{\zeta_{ij}^l + 4 \times \zeta_{ij}^m + \zeta_{ij}^u}{6} \dots\dots\dots (6)$$

In the above expression (equation 5), d is the number of experts and p, q is greater than zero numbers. Crisp value can be determined by using equation (6)

4. Analysis of Roadblocks

Roadblocks are identified in two categories, primary and secondary, from the various research articles as given in **Table 1**. There are five primary roadblocks categories, each with four sub categories, resulting in 20 secondary roadblocks. After finalizing the roadblocks, the ranking and comparisons data were collected from the four experts on linguistic scale using **Table 3** from industries and academia through a survey questionnaire on a linguistic scale. The rankings and comparisons data by experts are

given in **Table 4**. The following six models (one for primary and five for secondary roadblocks) were framed:

Model 1—Determination of local weights of primary roadblocks i.e., RR, ER, SR, TR, and MOR.

Model 2—Determination of local weights in regulatory roadblocks, i.e., RR1-RR4

Model 3—Determination of local weights in economical roadblocks, i.e., ER1-ER4

Model 4—Determination of local weights in social roadblocks, i.e., SR1-SR4

Model 5—Determination of local weights in technological roadblocks, i.e., TR1-TR4

Model 6—Determination of local weights in Management and organisational roadblocks, i.e., MOR1-MOR4

Table 4 Evaluation of primary and secondary roadblocks on Linguistic scale by Experts

Primary/ Secondary Roadblocks		Expert I	Expert II
RR, ER, SR, TR, MOR	Rank	RR > MOR= ER > TR > SR	RR =ER> MOR > TR > SR
	Comparisons	EI, WI, EI, FI, FI	EI, EI, FI, FI, VI
RR1-RR4	Rank	RR1>RR2>RR3>RR4	RR1>RR4>RR2>RR3
	Comparisons	EI, FI, VI, VI	EI, WI, VI, AI
ER1-ER4	Rank	ER1>ER3>ER2=ER4	ER1>ER2>ER3=ER4
	Comparisons	EI, WI, VI, EI	EI, WI, WI, EI
SR1-SR4	Rank	SR3>SR1>SR4>SR2	SR4>SR3>SR2>SR1
	Comparisons	EI, WI, FI, FI	EI, WI, WI, FI
TR1-TR4	Rank	TR1>TR4>TR2>TR3	TR1>TR2>TR4>TR3
	Comparisons	EI, WI, WI, WI	EI, FI, FI, AI
MOR1-MOR4	Rank	MOR2>MOR4>MOR1>MOR3	MOR2>MOR4>MOR3>MOR1
	Comparisons	EI, FI, FI, FI	EI, WI, FI, FI
Primary/secondary Roadblocks		Expert III	Expert IV
RR, ER, SR, TR, MOR	Rank	RR >MOR> TR > ER > SR	ER >RR> SR > MOR > TR
	Comparisons	EI, WI, VI, VI, AI	EI, FI, WI, VI, AI
RR1-RR4	Rank	RR1>RR4>RR2>RR3	RR2=RR1>RR3>RR4
	Comparisons	EI, WI, FI, AI	EI, EI, FI, VI
ER1-ER4	Rank	ER2>ER1>ER4>ER3	ER1>ER3>ER2>ER4
	Comparisons	EI, FI, FI, AI	EI, FI, WI, VI
SR1-SR4	Rank	SR4>SR2>SR3>SR1	SR4>SR3>SR2>SR1
	Comparisons	EI, FI, VI, VI	EI, WI, FI, VI
TR1-TR4	Rank	TR2>TR1>TR3>TR4	TR2>TR4>TR3>TR1

For a better understanding, Model I by expert I is solved here using Fuzzy FUCOM method and Fuzzy Bonferroni Mean Operator. For the sake of simplicity while solving equations, let weights of primary roadblocks as

$$RR = w_1, ER = w_2, SR = w_3, TR = w_4, MOR = w_5,$$

Ranking and comparisons done by expert I for primary roadblocks are given as follows:

$$\text{Ranking} \rightarrow RR (w_1) > MOR (w_5) = ER (w_2) > TR (w_4) > SR (w_3)$$

$$\text{Comparisons} \rightarrow EI, WI, EI, FI, FI$$

As there are five primary roadblocks, so their total combinations can be computed by using equation (1)

$$\text{Total Combination Conditions} = {}^nC_2 = \frac{n(n-1)}{2} = \frac{5 \times 4}{2} = 10$$

The comparative weights given by expert I can be determined using equation (2), (3) and (4) for the main roadblocks are:

$$\tilde{\varphi}_{w_1/w_5} = \left(\frac{2}{3}, 1, \frac{3}{2}\right), \quad \tilde{\varphi}_{w_5/w_2} = (1, 1, 1), \quad \tilde{\varphi}_{w_2/w_4} = \left(\frac{3}{2}, 2, \frac{5}{2}\right), \quad \tilde{\varphi}_{w_4/w_3} = \left(\frac{3}{2}, 2, \frac{5}{2}\right)$$

And the transitive condition can be obtained using equation (5) as follows:

$$\tilde{\varphi}_{w_1/w_2} = \tilde{\varphi}_{w_1/w_5} \otimes \tilde{\varphi}_{w_5/w_2} = \left(\frac{2}{3}, 1, \frac{3}{2}\right) \otimes (1, 1, 1) = \left(\frac{2}{3}, 1, \frac{3}{2}\right)$$

$$\tilde{\varphi}_{w_5/w_4} = \tilde{\varphi}_{w_5/w_2} \otimes \tilde{\varphi}_{w_2/w_4} = (1, 1, 1) \otimes \left(\frac{3}{2}, 2, \frac{5}{2}\right) = \left(\frac{3}{2}, 2, \frac{5}{2}\right)$$

$$\tilde{\varphi}_{w_2/w_3} = \tilde{\varphi}_{w_2/w_4} \otimes \tilde{\varphi}_{w_4/w_3} = \left(\frac{3}{2}, 2, \frac{5}{2}\right) \otimes \left(\frac{3}{2}, 2, \frac{5}{2}\right) = \left(\frac{9}{4}, 4, \frac{25}{4}\right)$$

$$\tilde{\varphi}_{w_1/w_3} = \tilde{\varphi}_{w_1/w_2} \otimes \tilde{\varphi}_{w_2/w_3} = \left(\frac{2}{3}, 1, \frac{3}{2}\right) \otimes \left(\frac{9}{4}, 4, \frac{25}{4}\right) = \left(\frac{3}{2}, 4, \frac{75}{8}\right)$$

$$\tilde{\varphi}_{w_1/w_4} = \tilde{\varphi}_{w_1/w_5} \otimes \tilde{\varphi}_{w_5/w_4} = \left(\frac{2}{3}, 1, \frac{3}{2}\right) \otimes \left(\frac{3}{2}, 2, \frac{5}{2}\right) = \left(1, 2, \frac{15}{4}\right)$$

$$\tilde{\varphi}_{w_5/w_3} = \tilde{\varphi}_{w_5/w_4} \otimes \tilde{\varphi}_{w_4/w_3} = \left(\frac{3}{2}, 2, \frac{5}{2}\right) \otimes \left(\frac{3}{2}, 2, \frac{5}{2}\right) = \left(\frac{9}{4}, 4, \frac{25}{4}\right)$$

Using the above relationship between weights, NLPP has been formulated and solved using Lingo 20 software.

Expert I – Primary Roadblocks NLPP

Min χ

Subjected to

$$\begin{array}{lll}
 \left| w_1^l - \frac{2}{3} w_5^u \right| \leq \chi; & |w_1^m - w_5^m| \leq \chi; & \left| w_1^u - \frac{3}{2} w_5^l \right| \leq \chi; \\
 \left| w_5^l - w_2^u \right| \leq \chi; & |w_5^m - w_2^m| \leq \chi; & \left| w_5^u - w_2^l \right| \leq \chi; \\
 \left| w_2^l - \frac{3}{2} w_4^u \right| \leq \chi; & |w_2^m - 2w_4^m| \leq \chi; & \left| w_2^u - \frac{5}{2} w_4^l \right| \leq \chi; \\
 \left| w_4^l - \frac{3}{2} w_3^u \right| \leq \chi; & |w_4^m - 2w_3^m| \leq \chi; & \left| w_4^u - \frac{5}{2} w_3^l \right| \leq \chi; \\
 \left| w_1^l - \frac{2}{3} w_2^u \right| \leq \chi; & |w_1^m - w_2^m| \leq \chi; & \left| w_1^u - \frac{3}{2} w_2^l \right| \leq \chi; \\
 \left| w_5^l - \frac{3}{2} w_4^u \right| \leq \chi; & |w_5^m - 2w_4^m| \leq \chi; & \left| w_5^u - \frac{5}{2} w_4^l \right| \leq \chi; \\
 \left| w_2^l - \frac{9}{4} w_3^u \right| \leq \chi; & |w_2^m - 4w_3^m| \leq \chi; & \left| w_2^u - \frac{25}{4} w_3^l \right| \leq \chi; \\
 \left| w_1^l - \frac{3}{2} w_3^u \right| \leq \chi; & |w_1^m - 4w_3^m| \leq \chi; & \left| w_1^u - \frac{75}{8} w_3^l \right| \leq \chi; \\
 \left| w_1^l - w_4^u \right| \leq \chi; & |w_1^m - 2w_4^m| \leq \chi; & \left| w_1^u - \frac{15}{4} w_4^l \right| \leq \chi; \\
 \left| w_5^l - \frac{9}{4} w_3^u \right| \leq \chi; & |w_5^m - 4w_3^m| \leq \chi; & \left| w_5^u - \frac{25}{4} w_3^l \right| \leq \chi;
 \end{array}$$

$$\frac{1}{6} \sum_{j=1}^5 (w_j^l + 4w_j^m + w_j^u) = 1;$$

$$w_j^l \leq w_j^m \leq w_j^u; j = 1, \dots, 5$$

$$w_j^l, w_j^m, w_j^u \geq 0; j = 1, \dots, 5$$

After solving the above NLPP, optimal weights for primary roadblocks obtained as

$$\omega_1 = (0.1649, 0.2898, 0.3781), \quad \omega_2 = (0.2332, 0.2615, 0.2615),$$

$$\omega_3 = (0.0433, 0.0724, 0.0911), \quad \omega_4 = (0.1084, 0.1366, 0.1366),$$

$$\omega_5 = (0.2332, 0.2615, 0.2615)$$

Table 5 Fuzzy weights of primary and secondary roadblocks

	Expert I		Expert II		Expert III		Expert IV	
	Fuzzy Weights	χ	Fuzzy Weights	χ	Fuzzy Weights	χ	Fuzzy Weights	χ
RR	(0.1649, 0.2898, 0.3781)	.03	(0.2994, 0.3478, 0.3478)	.05	(0.2459, 0.4242, 0.559)	.02	(0.2021, 0.2206, 0.2206)	.05
ER	(0.2332, 0.2615, 0.2615)		(0.2994, 0.3478, 0.3478)		(0.0317, 0.0474, 0.0535)		(0.2753, 0.4952, 0.5607)	
SR	(0.0433, 0.0724, 0.0911)		(0.0181, 0.033, 0.0446)		(0.007, 0.0118, 0.0153)		(0.1643, 0.2198, 0.2198)	
TR	(0.1084, 0.1366, 0.1366)		(0.0634, 0.099, 0.1116)		(0.1108, 0.1338, 0.1338)		(0.0104, 0.0229, 0.0251)	
MOR	(0.2332, 0.2615, 0.2615)		(0.1584, 0.198, 0.2067)		(0.3574, 0.4032, 0.4032)		(0.0469, 0.0879, 0.0879)	
RR1	(0.4093, 0.5915, 0.7182)	.02	(0.2517, 0.4343, 0.5723)	.02	(0.2227, 0.4073, 0.5107)	.04	(0.3384, 0.375, 0.375)	.04
RR2	(0.2794, 0.286, 0.286)		(0.1135, 0.1369, 0.1369)		(0.1463, 0.1845, 0.1845)		(0.3384, 0.375, 0.375)	
RR3	(0.0843, 0.1019, 0.1039)		(0.0252, 0.0364, 0.0391)		(0.0325, 0.0527, 0.0527)		(0.1646, 0.2012, 0.2012)	
RR4	(0.0241, 0.03395, 0.0416)		(0.3659, 0.4128, 0.4128)		(0.315, 0.391, 0.391)		(0.047, 0.0686, 0.0805)	
ER1	(0.2293, 0.3956, 0.5212)	.02	(0.1544, 0.2841, 0.3602)	.05	(0.2568, 0.2683, 0.2683)	.03	(0.2813, 0.506, 0.5729)	.06
ER2	(0.1034, 0.1247, 0.1247)		(0.2063, 0.2841, 0.3078)		(0.3679, 0.571, 0.6764)		(0.1679, 0.2246, 0.2246)	
ER3	(0.3332, 0.376, 0.376)		(0.1826, 0.2333, 0.2333)		(0.0253, 0.0378, 0.0423)		(0.2065, 0.2254, 0.2254)	

ER4	(0.1034, 0.1247, 0.1247)		(0.1826, 0.2333, 0.2333)		(0.1137, 0.1482, 0.1482)		(0.0479, 0.0899, 0.0899)	
SR1	(0.2993, 0.3719, 0.3719)	.04	(0.0805, 0.1564, 0.1713)	.06	(0.0241, 0.03395, 0.0416)	.02	(0.0411, 0.0704, 0.0725)	.04
SR2	(0.0556, 0.102, 0.1169)		(0.2011, 0.257, 0.257)		(0.2794, 0.286, 0.286)		(0.1438, 0.1814, 0.1814)	
SR3	(0.2116, 0.387, 0.4852)		(0.2272, 0.3129, 0.339)		(0.0843, 0.1019, 0.1039)		(0.3096, 0.3846, 0.3846)	
SR4	(0.1391, 0.1753, 0.1753)		(0.1701, 0.3129, 0.3967)		(0.4093, 0.5915, 0.7182)		(0.2189, 0.4002, 0.5019)	
TR1	(0.1481, 0.2723, 0.3453)	.05	(0.3679, 0.571, 0.6764)	.03	(0.2724, 0.3385, 0.3385)	.03	(0.0361, 0.0541, 0.0706)	.01
TR2	(0.1751, 0.2237, 0.2237)		(0.2568, 0.2683, 0.2683)		(0.1926, 0.3523, 0.4417)		(0.2625, 0.4324, 0.5944)	
TR3	(0.1167, 0.2723, 0.3356)		(0.0253, 0.0378, 0.0423)		(0.1266, 0.1596, 0.1596)		(0.0904, 0.1059, 0.1059)	
TR4	(0.1978, 0.2723, 0.295)		(0.1137, 0.1482, 0.1482)		(0.0844, 0.1858, 0.2394)		(0.386, 0.417, 0.417)	
MOR1	(0.1096, 0.1428, 0.1428)	.03	(0.0556, 0.102, 0.1169)	.04	(0.1679, 0.2246, 0.2246)	.06	(0.0964, 0.1807, 0.2651)	.03
MOR2	(0.3544, 0.5501, 0.6516)		(0.2116, 0.387, 0.4852)		(0.2065, 0.2254, 0.2254)		(0.2972, 0.3293, 0.3293)	
MOR3	(0.0438, 0.0729, 0.0952)		(0.1391, 0.1754, 0.1754)		(0.048, 0.0899, 0.0899)		(0.1446, 0.1767, 0.1767)	
MOR4	(0.2474, 0.2584, 0.2584)		(0.2993, 0.3719, 0.3719)		(0.2816, 0.506, 0.5729)		(0.2972, 0.3293, 0.3293)	

Likewise, other weights of primary and secondary roadblocks can be determined by solving the NLPPs. The solution of all NLPPs, which represents the fuzzy weights of primary and secondary roadblocks, is given in **Table 5**. After getting all the weights the aggregation is done by using Fuzzy Bonferroni Mean Operator as follows by taking $p=q=1$ using equation (6):

$$\begin{aligned}\zeta_{ij}^l &= \left(\frac{1}{d(d-1)} \cdot \sum_{i,j=1, i \neq j}^d (\zeta_j^l)^p \otimes (\zeta_j^l)^q \right)^{\frac{1}{p+q}} \\ &= \left(\frac{1}{4(4-1)} \cdot (.1649^1 \times .2332^1 + .1649^1 \times .0433^1 \right. \\ &\quad + .1649^1 \times .1084^1 + .1649^1 \times .2332^1 + .2332^1 \times .1649^1 \\ &\quad + .2332^1 \times .0433^1 + .2332^1 \times .1084^1 + .2332^1 \times .2332^1 + .0433^1 \times .1649^1 \\ &\quad + .0433^1 \times .2332^1 + .0433^1 \times .1084^1 + .0433^1 \times .2332^1 + .1084^1 \times .1649^1 \\ &\quad + .1084^1 \times .2332^1 + .1084^1 \times .0433^1 + .1084^1 \times .2332^1 + .2332^1 \times .1649^1 \\ &\quad \left. + .2332^1 \times .0433^1 + .2332^1 \times .1084^1 + .2332^1 \times .2332^1) \right)^{\frac{1}{1+1}} = .2262\end{aligned}$$

The Crisp number is calculated for RR using equation (7) as

$$= \frac{.2262 + 4 \times .3177 + .3698}{6} = .3111$$

The Normalized weight of RR is obtained using equation (8) as

$$= \frac{.3111}{.3111 + .2629 + .0677 + .0909 + .2326} = .3259$$

Likewise, we can calculate the above values for all the primary and secondary roadblocks. All these values are given in **Table 6**. For better illustration global weights of primary and secondary roadblocks are drawn in **Figure 2** and **Figure 3** respectively.

Table 6 Global and local weights of roadblocks

Roadblocks (Primary and Secondary)	l	m	u	Crisp number	Normalized Weights (Local)	Normalized Weight (Global)	Ranking
RR	0.2262	0.3177	0.3698	0.3111	0.3259	0.3259	P1

ER	0.2009	0.2723	0.2873	0.2629	0.2754	0.2754	P2
SR	0.0456	0.0700	0.0810	0.0677	0.0710	0.0710	P5
TR	0.0693	0.0944	0.0984	0.0909	0.0952	0.0952	P4
MOR	0.1880	0.2284	0.2307	0.2220	0.2326	0.2326	P3
RR1	0.3026	0.4495	0.5394	0.4400	0.4582	0.1493	S1
RR2	0.2128	0.2398	0.2398	0.2353	0.2450	0.0798	S5
RR3	0.0696	0.0908	0.0922	0.0875	0.0911	0.0297	S12
RR4	0.1657	0.2026	0.2093	0.1975	0.2057	0.0670	S7
ER1	0.2288	0.3593	0.4248	0.3485	0.3607	0.0993	S2
ER2	0.2037	0.2855	0.3109	0.2761	0.2858	0.0787	S6
ER3	0.1759	0.2068	0.2083	0.2019	0.2090	0.0576	S8
ER4	0.1084	0.1459	0.1459	0.1396	0.1445	0.0398	S9
SR1	0.0911	0.1389	0.1465	0.1322	0.1380	0.0098	S20
SR2	0.1633	0.2024	0.2068	0.1966	0.2053	0.0146	S18
SR3	0.2029	0.2889	0.3181	0.2794	0.2917	0.0207	S17
SR4	0.2264	0.3596	0.4336	0.3497	0.3651	0.0259	S15
TR1	0.1930	0.2901	0.3355	0.2815	0.2928	0.0279	S14
TR2	0.2206	0.3158	0.3725	0.3094	0.3218	0.0306	S11
TR3	0.0868	0.1351	0.1480	0.1292	0.1344	0.0128	S19
TR4	0.1833	0.2488	0.2691	0.2412	0.2510	0.0239	S16
MOR1	0.1048	0.1604	0.1841	0.1551	0.1575	0.0366	S10
MOR2	0.2650	0.3667	0.4125	0.3574	0.3629	0.0844	S3
MOR3	0.0897	0.1257	0.1321	0.1208	0.1227	0.0285	S13
MOR4	0.2811	0.3627	0.3771	0.3515	0.3569	0.0830	S4

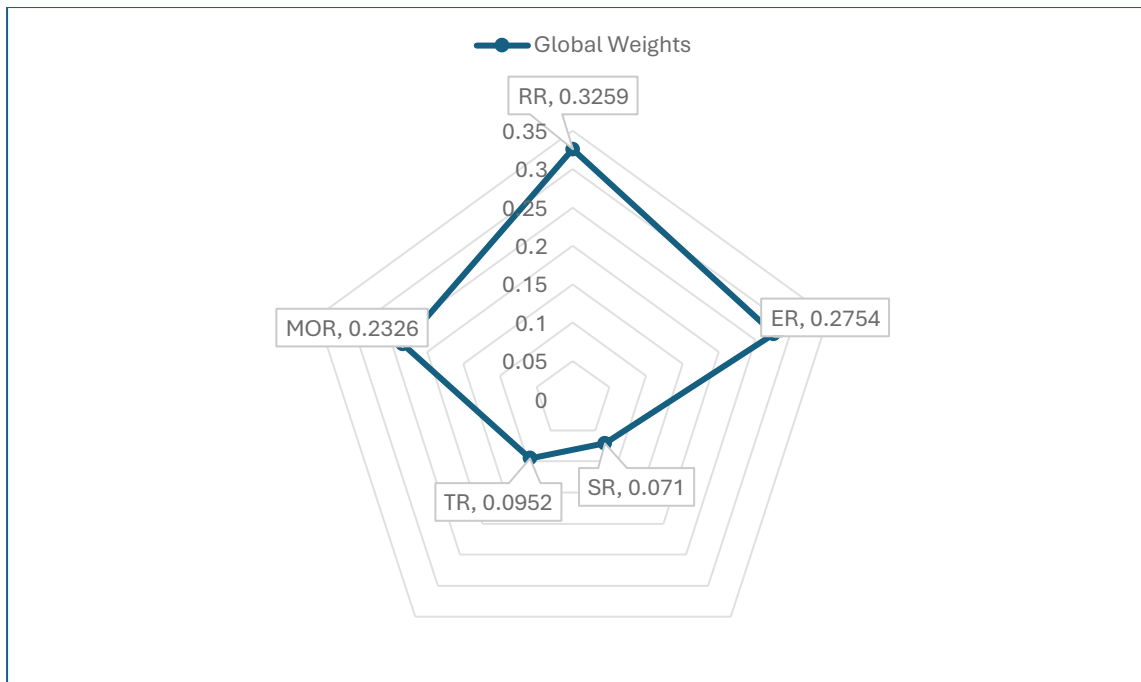


Figure 2 Global weight of primary roadblocks

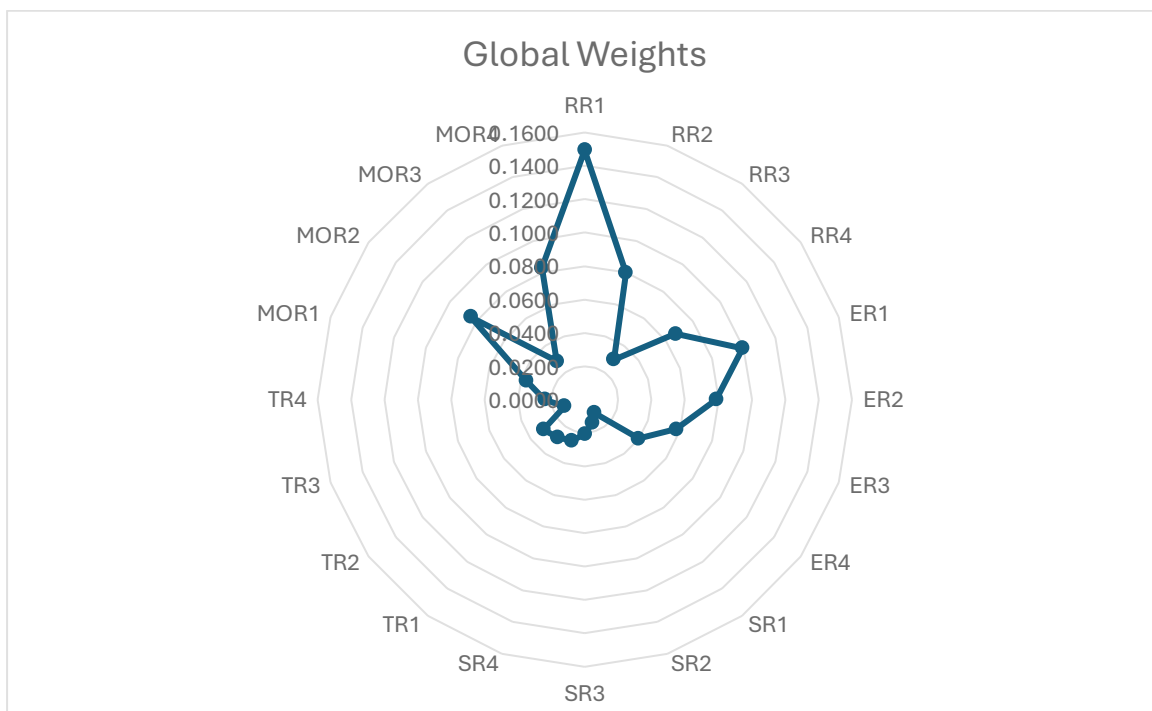


Figure 3 Global weight of secondary roadblocks

This section covers experts' analyses of the primary and secondary obstacles to implementing a circular supply chain. Selected twenty roadblocks were divided into five primary groups to evaluate their priority. The primary impediments examined in this study are the regulatory,

economic, social, technological, and management & organization barriers. Each of these sub-categories has four subgroups.

Sensitivity Analysis

It is necessary to assess the obtained solution's robustness to choose the best solution from the evaluated set ultimately. It is crucial to use robustness analysis to investigate how subjectively chosen model parameters affect the results (Nila & Roy, 2023). Many researchers advocate for sensitivity analysis to validate results, but there is no specific method to do sensitivity analysis (Ecer, 2021). In this paper, we have used the Bonferroni Mean operator for sensitivity analysis. The values of p and q parameters are changed from 1 to 20. Firstly, we took the value of p as one and changed q from 1 to 20; secondly, we took q as one and then changed the value of p from 1 to 20; and last, we changed p and q simultaneously from 1 to 20, resulting in 58 scenarios. All these values are drawn in **Figure 4**.

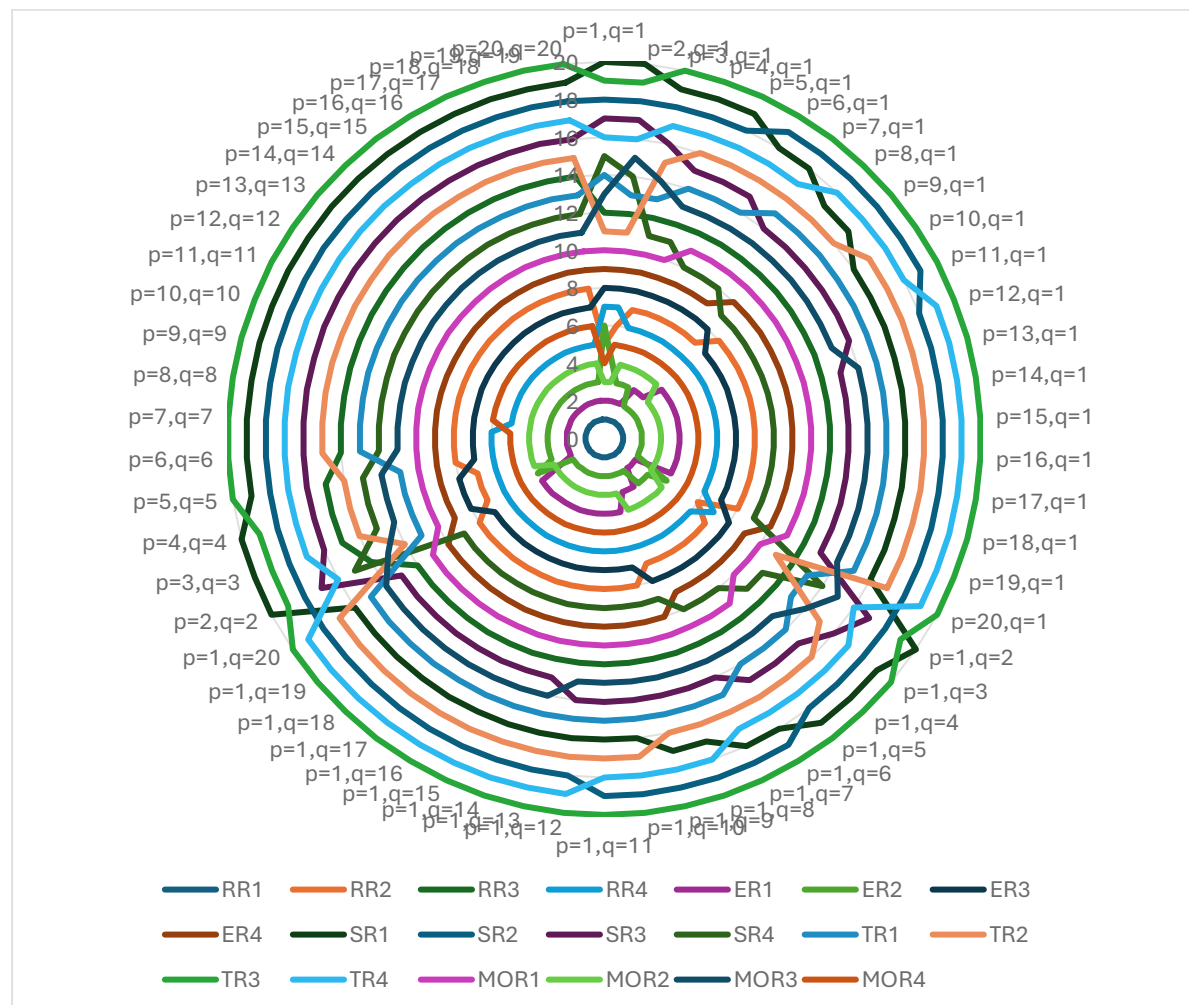


Figure 4 Sensitivity Analysis by changing values of p and q

The sensitivity analysis concludes that variations in the p and q parameter values impact the roadblock weights in the FUCOM-F'B framework. Consequently, it is recommended that the values of p and q be assumed to be 1 in real-world problems. The decision-making process becomes easier to understand and the internal relationships between the roadblocks can be taken into consideration if $p = q = 1$.

From the **Figure 4**, it has been observed that the first ranked roadblock, which is lack of precise and consistent guidelines, remains on top in all the scenarios, and the last ranked roadblock fluctuates between two roadblocks, i.e., lack of high-tech in reverse logistics and Insufficient interpersonal communication with customers/patients. This further confirms the robustness of the prioritization of roadblocks.

5. Results and Discussions

The main roadblocks are ranked in order of priority as follows: social (SR), technological, organizational, regulatory (RR), economical (ER), and management. According to research findings, the regulatory obstacle was the most essential roadblock, with a worldwide weight value of 0.3259 compared to other roadblocks. With a global weight of 0.2752, the regulatory roadblocks are slightly ahead of the second-ranked roadblock, namely the economic roadblocks. Additionally, it is noted that the management and organizational roadblocks, which are ranked third, are behind somewhat, with a worldwide weight of 0.2326. Moreover, it is noted that, with global weights of 0.0952 and 0.0710, respectively, the technological and social roadblocks are noticeably lagging the other three.

The primary roadblocks are listed along their priority as follows: regulatory (RR), economical (ER), management and organizational, technological, and social (SR), regarding research findings regarding the regulatory roadblock with the value of global weight 0.3259 compared with other roadblocks, found to be the most critical roadblock. However, the second-ranked roadblock, i.e., economic roadblocks, does not lag much the regulatory roadblock with a global weight of 0.2752. It is also observed that the third-placed roadblock, i.e., management and organizational roadblock, is lagging moderately with the global weight of 0.2326. In continuation with this, it is also observed that technology and social roadblocks are

significantly lagging the other three roadblocks with global weights of 0.0952 and 0.0710, respectively.

The roadblocks of the circular healthcare supply chain have been identified in the other studies with different parameters and contexts. For example, (Dixit & Dutta, 2024; Kazançoğlu et al., 2021a; Mahjoob et al., 2023a) identified policy roadblocks as the most critical roadblock and social roadblocks as the least crucial roadblock for implementing circular economy in the healthcare sector of Türkiye. Jafarzadeh Ghouschi et al. (2022) reveal that lack of leadership commitment is the most critical roadblock when finding barriers to implementing a circular economy in designing a sustainable waste management system. While evaluating the supply chain barriers (Lahane & Kant, 2021), it was found that strategic and regulatory barriers were the most predominant barriers for the Indian industries. As other studies were done in different countries or sectors, they also identified the regulatory roadblock as the most critical for implementing circular supply, as per our study.

While analyzing the result of secondary roadblock categories of regulatory roadblocks, which appears as the most prominent roadblock with the highest global weights, has four sub-categories: lack of precise and consistent guidelines (RR1, 0.1493), lack of favorable tax policies for promoting CHSCM (RR2, 0.0798), non-existence of suitable performance measurement system (RR3, 0.0297), unclear vision regarding product recovery in CHSC (RR4, 0.0670). Our analysis shows that the lack of precise and consistent guidelines is the most critical roadblock supported by other researchers (Agrawal et al., 2023; Karloopia & Agrawal, 2024; Kazançoğlu et al., 2021b; Khandelwal & Barua, 2020; Lahane & Kant, 2021; Mahjoob et al., 2023b; Patra et al., 2024), while non-existence of suitable performance measurement system is the least critical in regulatory roadblock category. Concerning the finding about the economic roadblock, the global ranking is as follows: high upfront investment costs (ER1, 0.0993), short-term perspective towards financial benefits (ER2, 0.0787), lack of economic capabilities and resources on environmental investments (ER3, 0.0576), Higher sales price of recycled products (ER4, 0.0398). In this category, high upfront investment costs become the most predominant roadblock, as suggested by (Çıkmak & Kesici, 2023; Heeres et al., 2023; Karbassi Yazdi et al., 2022; S. Mishra et al., 2024). As far as social roadblock is concerned, it is also categorized into four sub-categories with global weights: Insufficient interpersonal communication with customers/patients (SR1, 0.0098), Hospital culture and reluctance to change (SR2, 0.0146), Lack of CE awareness in healthcare (SR3, 0.0207), Safety, security, quality and infection risk of remanufactured, recycled and reused product (SR4, 0.0259). As

people are becoming more aware of the environment, hospitals and patients are ready for the change for sustainability as suggested by various researchers (Karbassi Yazdi et al., 2022; Kazançoğlu et al., 2021b; Lahane & Kant, 2021; Mahjoob et al., 2023a). .

While considering the analysis of secondary roadblocks of technology roadblocks, scarcity of skilled human resources and lack of training with a global weight of 0.0306 is the most prominent, which is also justified by the study done by (Almutairi et al., 2021; Heeres et al., 2023) while finding the barriers in the healthcare supply chain in Saudi Arabia which is also a developing country like India. The global weights of other secondary roadblocks are lack of easily accessible data for tracking and tracing (TR1, 0.0279), lack of high-tech in reverse logistics (TR3, 0.0128), and lack of implementation of new technologies in service (TR4, 0.0239). Analyzing the secondary roadblocks of management and organizational category, it is found that lack of leadership commitment and established standards and strategies for CE activities in healthcare, with global scores of 0.0844 and 0.0833, respectively, have nearly equal importance. The result obtained was verified by earlier research done by (Çıkmak & Kesici, 2023; Jafarzadeh Ghouschi et al., 2022; Karloopia & Agrawal, 2024; Kazancoglu et al., 2020; Lahane & Kant, 2021; Mukherjee et al., 2023). This indicates that to adopt a circular economy in healthcare; top management should take responsibility on their shoulders and create strategies for adopting CE activities in their industry. It has also been noted that the first roadblock, the lack of precise and consistent guidelines, continues to be at the top of the list in every one of the instances. In conclusion, the last bottleneck is a balancing act between two roadblocks, which are a lack of high-tech in reverse logistics and an inadequate amount of human engagement with consumers and patients. This offers more proof that the prioritization of obstacles is an approach that may be successfully implemented.

6. Research Implications

Unsustainable development in the healthcare sector is a significant concern due to the extensive use of single-use medical devices. So, industrialists can incorporate the circular economy concept to retard this practice. This study explores and prioritizes twenty secondary roadblocks categorized into five primary roadblocks. Industrialist can identify and examine the readiness for implementation of a circular economy in their industries by taking the help of prioritized roadblocks in the current study. It is an arduous task for the industrialist to deal with all the

suggested roadblocks simultaneously, so by taking the help of prioritized roadblocks, one can identify which barriers should combat first to start circular economy practices in their industry.

Practical Implications

The finding of this study suggests that regulatory roadblock is a more critical roadblock in adopting the circular economy in the healthcare supply chain. It is expected that the government should formulate precise and consistent guidelines for the implementation of a circular economy in the healthcare supply chain. In addition, for faster implementation, tax rebate policy should be framed for the industries that are taking the initiative to implement a circular economy in their system. That will enhance the motivation of healthcare industries to become green and circular and contribute to sustainability in the healthcare sector. Government agencies should also take initiatives to create awareness about the circular economy among all the stakeholders. The researcher's and academician's industry-academia interaction can also help industry people better understand the concept of circular economy and its benefits in the long run and guide them in not sticking to short-term goals.

Social Implications

As the study results suggest, lack of CE awareness in healthcare and hospital culture and reluctance to change is the least concerning roadblocks. Still, it shows that society and industries are more concerned with environmental issues. Industries can also increase their sales by having a clean and green image compared with their competitors. The infection risk due to using recycled and reused products is a significant concern in healthcare. This can be eliminated by taking care of quality measures of the process and product used. By doing so, the scarcity of medical devices can be eliminated, which enhances the quality of life and standard of living. Global adoption of circular economy principles has increased recently, driven by an urgency to attain the 17 Sustainable Development Goals (SDGs) (Patra et al.,2024). By using circularity in the healthcare sector, it assists practitioners, policymakers, and decision-makers in achieving sustainable development goals (SDG) such as good health and well-being (SDG3), Industry, innovation, and infrastructure (SDG 9) and partnerships for the goals (SDG17).

7. Conclusion

The present research is intended to recognize and prioritize the roadblocks of circular supply chains in healthcare industries. Five primary roadblocks categorized into four secondary roadblocks in each category have been identified by literature review and healthcare industry experts. The fuzzy FUCOM method is used to find local and global weights of the identified roadblocks, which helped to prioritize these concerning their importance. The results show that regulatory roadblocks are the most critical roadblocks followed by economical and management roadblocks. The result also reveals that the lack of precise and consistent guidelines is one of the most predominant roadblocks in all the secondary roadblocks. The findings of this study offer policymakers a helpful path for creating standard rules, policies, and regulations that would facilitate the effective implementation of CHSC operations in the healthcare sector. The managers of other Indian industries, like textile, automobile, etc., can also benefit from the result of the study, as the implementation of a circular economy is in the developing phase in India. The textile manager can reduce and reuse the material by using advanced technologies in reverse logistics and service. Using digital technologies to track and trace data can improve the supply chain's resilience.

In the recent past, the behavior of organizations and society towards achieving CE has improved as people are becoming environmentally conscious. The industries and people should follow the rules and regulations. To sustain in the global market, the industries are trying to reduce their carbon emissions, for that circular economy is to be implemented necessarily.

Potential Limitations and Future Research

Certain limitations to this scientific endeavor may open new directions for investigators in the future. This study may be prejudiced and have an impact on the outcome because it is based on the subjective judgments of experts. However, by considering fuzzy numbers followed by sensitivity analysis, we have minimized the possible cause of error in subjective judgment. However, one can generalize through structure equation modeling or simulation-based models. The present study is done specifically for circular supply chains in healthcare industries. It can be extended to other specific industries like agriculture, food, construction, and textiles. Moreover, the present study has been performed in developing nations, specifically India, so in the future, it can be done in other geographical locations.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to restrictions, e.g., they contain information that could compromise the privacy of research participants.

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