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A Hybrid Fuzzy AHP – Fuzzy TOPSIS Approach for Prioritizing Critical Enablers of Responsive Healthcare Supply Chain Management in India

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Abstract: This research identifies, evaluates, and ranks the critical enablers of responsive healthcare supply chain management (RHSCM) in the Indian healthcare context. The study employs an integrated Fuzzy Analytic Hierarchy Process (FAHP) with Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) methodology to analyse twelve sub-enablers within four main enabler categories. Results demonstrate that Information Transparency (global weight: 0.160), Real-time Supply Chain Visibility (global weight: 0.134), and Strategic Commitment and Resource Availability (global weight: 0.144) are the three most critical enablers for enhancing RHSCM performance. Both FAHP and FTOPSIS rankings produced consistent results with closeness coefficients of 0.613, 0.534, and 0.581, respectively, for these top enablers. The Technology and Information-Centric category received the highest importance weight (0.42) among the four main enabler categories. This research contributes significant analytical insights for healthcare administrators and policymakers to effectively prioritize investments and strategic interventions in RHSCM implementation within the resource-constrained Indian healthcare environment.

Keywords: Healthcare supply chain management; Responsive healthcare supply chain; Fuzzy AHP; Fuzzy TOPSIS; Multi-criteria decision making methods.

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1. Introduction

The healthcare supply chain (HSC) functions as a complex and critical system responsible for delivering pharmaceuticals and medical supplies to patients efficiently and effectively. Recent disruptions, particularly from the COVID-19 pandemic, have highlighted vulnerabilities in healthcare supply chains worldwide and emphasized the urgent need for enhancing responsiveness (Dwivedi et al., 2022). Healthcare supply chain management encompasses the integration of information, logistics, and financial flows to deliver medical products and services from suppliers to end users while optimizing cost, quality, and performance metrics (Yanamandra et al., 2023). In India, the world's most populous country with over 1.42 billion people, healthcare supply chain challenges are exacerbated by complex public-private sectoral dynamics, resource constraints, and dramatic demand fluctuations (Sharma and Shanker, 2023). Recent research has emphasized the increasing complexity and critical importance of healthcare supply chains. Luthra et al. (2021) applied an integrated ISM-ANP approach to analyze barriers to sustainable healthcare supply chain implementation, identifying lack of government support and financial constraints as significant barriers in developing economies. Their work demonstrated how policy interventions could overcome these barriers through a structured analytical approach. Similarly, Nandi et al. (2021) evaluated the impact of digital technologies on healthcare supply chain performance using structural equation modeling with data from 312 Indian healthcare organizations, finding that blockchain and IoT technologies significantly improved supply chain visibility ($\beta=0.42$, $p<0.01$) and responsiveness ($\beta=0.38$, $p<0.01$). Kumar et al. (2022) conducted an extensive systematic review of 172 articles on healthcare supply chain management, revealing that only 17% of studies focused on responsiveness factors, indicating a significant research gap. Their bibliometric analysis showed that research interest in healthcare supply chain responsiveness has increased by 215% since 2019, highlighting its growing importance.

Responsive healthcare supply chain management refers to the ability of the healthcare supply chain to rapidly adapt to changing demands, supply uncertainties, and environmental challenges (Bag et al., 2023). Dwivedi et al. (2022) conducted a mixed-method study examining 87 hospitals during the COVID-19 pandemic and found that healthcare organizations with responsive supply chains reduced stockout incidents by 64% compared to those with traditional supply chains. Their research identified information sharing capabilities as the most significant differentiator between high and low-performing supply chains. Venkatesh et al. (2023) analyzed data from 124 Indian healthcare providers and found that responsive healthcare supply chains reduced operational costs by 17.3% and improved service levels by 23.6% compared to conventional approaches. Their path analysis revealed that information technology integration (path coefficient=0.48) and collaborative partner networks

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(path coefficient=0.42) were the strongest predictors of supply chain responsiveness. Chowdhury et al. (2022) examined responsive supply chain practices in disaster management contexts, finding that organizations implementing real-time visibility technologies experienced 47% faster response times to demand surges. Their case studies of three Indian hospital networks demonstrated that information transparency reduced communication delays by an average of 76% during crisis situations.

Recent literature has identified various enablers that contribute to healthcare supply chain responsiveness. Sharma and Shanker (2023) identified 14 key enablers of responsive healthcare supply chains and found that technological integration, strategic partnerships, and human resource capabilities were most significant in their regression analysis ($R^2=0.67$, $p<0.001$). Their study of 27 Indian healthcare organizations showed that hospitals investing in these enablers reduced lead times by 41% on average. Bag et al. (2023) empirically investigated the impact of artificial intelligence and blockchain technologies on healthcare supply chain responsiveness using data from 217 healthcare providers. Their structural equation modeling revealed that these technologies enhanced information flow ($\beta=0.51$, $p<0.001$) and supply chain visibility ($\beta=0.47$, $p<0.001$), leading to a 28% improvement in overall responsiveness. Yadav et al. (2022) employed Delphi technique with 32 experts to identify critical success factors for healthcare supply chain responsiveness, finding that information systems integration, collaborative relationships, and resource commitment were consistently ranked in the top five factors across three rounds of evaluation (Kendall's W=0.78).

Multi-criteria decision-making (MCDM) methods have been increasingly applied in healthcare supply chain management to address complex decision problems. Abdel-Basset et al. (2023) applied a neutrosophic AHP-TOPSIS framework to prioritize sustainable healthcare supply chain practices and found that the integrated approach reduced decision uncertainty by 34% compared to traditional methods. Their validation with 18 decision-makers showed high consistency (CR<0.1) and reliability ($\alpha=0.82$). Moslem et al. (2022) demonstrated the effectiveness of fuzzy AHP for healthcare decision-making under uncertainty, achieving 27% higher accuracy in priority determination compared to crisp methods. Their sensitivity analysis confirmed the stability of results across varying fuzzy parameters, supporting the method's robustness for healthcare applications. Yanamandra et al. (2023) employed an integrated fuzzy DEMATEL-ANP approach to model the interdependencies between healthcare supply chain enablers, revealing that information-centric enablers had the highest prominence scores (0.842) and influence on other factors in the system. Their research provided quantitative evidence of the causal relationships between different enabler categories.Despite significant advances in healthcare supply chain management research,

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several gaps remain in the literature. Limited empirical studies specifically address RHSCM enablers in developing economies like India. There is a lack of integrated MCDM approaches that account for both hierarchical relationships and multi-criteria performance of RHSCM enablers. The literature shows insufficient attention to contextual factors affecting healthcare supply chain responsiveness in resource-constrained environments. Additionally, there is an absence of quantitative prioritization frameworks to guide strategic investment decisions in RHSCM implementation.

This research addresses these gaps by:

1. Developing the first integrated multi-criteria framework to identify, categorize, and prioritize RHSCM enablers specifically tailored to the Indian healthcare ecosystem

2. Employing an innovative combination of Fuzzy AHP and Fuzzy TOPSIS methodologies to handle the uncertainty inherent in healthcare supply chain decision-making

3. Generating empirically validated weights and rankings of enablers to guide strategic investment decisions in RHSCM

The novelty of this research lies in its comprehensive identification and empirical evaluation of RHSCM enablers within a developing country context, providing decision-makers with a scientifically robust prioritization framework that accounts for both the hierarchical relationships between enablers and their performance across multiple criteria.

The specific objectives of this research are:

1. To identify key enablers of responsive HSCM in the Indian context through literature review and expert consultation.

2. To determine the relative importance (weights) of these enablers using FAHP.

3. To rank the enablers based on their significance using FTOPSIS.

4. To provide practical recommendations for healthcare organizations and policymakers to enhance HSCM responsiveness in India.

The following sections comprise this paper: Section 2 describes the materials and methodology employed in this study. Section 3 presents the results and analysis of the FAHP and FTOPSIS methods. Section 4 discusses the findings and their implications for RHSCM in India. This study ends with limitations and suggests new research paths to pursue in the conclusion section 5.

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2. Materials and Methodology

2.1 Identification of Enablers

Research literature and getting feedback from experts determined which elements enable responsive healthcare supply chain management. The evaluation resulted in twelve sub-enablers which fell under Technology and Information-Centric Enablers (TI) Integration and Collaboration Enablers (IC) Regulatory and Human Resource Enablers (RH) and Operational and Structural Enablers (OS). Table 1 presents the different enablers together with their specific coding systems.

2.2 Data Collection

Data for this study were collected through a structured questionnaire administered to experts in healthcare supply chain management in India. The experts were selected based on their experience and expertise in healthcare supply chain operations, policy-making, and administration. A total of 15 experts with an average experience of 12.5 years in healthcare supply chain management participated in the study. The questionnaire comprised two sections. The first section of the questionnaire collected information about expert demographics which included their job titles as well as their organizational affiliation and years of work experience together with their educational backgrounds. The second section consisted of nine-point fuzzy scale-based pair-wise comparison matrices for primary enabler categories and sub-enablers. The evaluation process relied on expert assessment of sub-enablers through five evaluation criteria (effectiveness, feasibility, sustainability, cost-efficiency and adaptability) with seven-point fuzzy scales used for FTOPSIS analysis.

2.3 Fuzzy Set Theory

Zadeh introduced fuzzy set theory in 1965 to create a mathematical system which addresses uncertain and vague conditions in decision processes. Fuzzy set theory operates differently than classical set theory by addressing the problem of elements belonging to sets to a certain degree. The methodology effectively tackles the interpretation problems which naturally occur with human decision-making.

The research adopts triangular fuzzy numbers (TFNs) as the method to represent linguistic variables within both pairwise comparison and evaluation contexts. The definition of a triangular fuzzy number consists of three components (l, m, u) representing the lower value and middle value and upper value of the fuzzy number respectively. Nine point scale linguistic is used for FAHP pairwise comparisons and five point scale is used for rating the enablers in the FTOPSIS approach.

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2.4 Fuzzy Analytic Hierarchy Process (FAHP)

The fuzzy analytical hierarchy process (FAHP) develops traditional AHP methodology through combining fuzzy sets with decision-making processes to handle decision uncertainty and imprecision. The study uses the extent analysis version of FAHP methodology (Moslem, S.et al. 2022). The FAHP method follows these specific steps for execution.

Step 1: Construction of fuzzy pairwise comparison matrices

The pairwise matrix gets developed through expert-based evaluations. The expert provides individual ratings for every element through their personal evaluation process.

Step 2: Aggregated the pairwise comparison matrix

All judgment data comes together within one single matrix system

Step 3: Calculation of fuzzy weights

The geometric mean method converts fuzzy comparison matrices (FCMs) from each enabler and sub-enabler into crisp comparison matrices (CCMs).

Step 4: Defuzzification of Matrix

The Centroid Defuzzification formula is used for defuzzification of fuzzy numbers for calculating the weight of enablers and sub- enablers.

$$x = \frac{z+y+x}{3} \qquad (1)$$

Step 5: Carry out the check for consistency

The eigenvalue has a a crucial role in ensuring the consistency of the FAHP. If the consistency ratio (CR) exceeds 0.1, the pairwise comparison matrix can be considered inconsistent.

Table 1: Enablers of Responsive Healthcare Supply Chain Management in India

S. N.	Enablers	Sub-Enabler	Code	Brief Description	Sources

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1	Technology and Information-Centric Enablers	Integration of Advanced Technologies and IT-Enabled Systems	TI_1	IT-enabled systems help store and manage patient data through digital databases yet patient care receives improvements from integrated advanced digital technologies such as IoT, AIML, blockchain and cloud computing.	Willis et al., (2016). Chakraborty et al., (2019).
		Data Quality and Sharing	TI_2	Accuracy, completeness, and accessibility of data shared between supply chain partners	Olawade, D. B. et al. (2024).
		Real-time Supply Chain Visibility	TI_3	Ability to track and monitor inventory, orders, and shipments in real-time	Jamwal et al. (2021), Chakraborty et al., (2019)
		Information transparency	TI_4	The system builds responsive operations through its establishment of effective stakeholder connections.	Guo et al. (2022), Kamble et al. (2018).
2	Integration and Collaboration Enablers	Strategic commitment and resource availability	IC_1	Top management establishes environmental awareness through resource allocation of financial and technical elements and performs continuous objective evaluation and plan adaptation.	Martın-Gomez et al. (2019), Luthra et al. (2018)
		Collaboration with Healthcare Partners	IC_2	Supply chain partners must collaborate to achieve real-time data exchange between different parts of the supply chain.	Presseau et al. (2017) and McMenamin and Mannion (2017).
		Customer and supplier integration	IC_3	Long-term customer-supplier integration enables efficient collaborative decision-making for inventory management along with planning and forecasting which	Kumar et al. (2020), O'Connor et al. (2020).

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				results in better HSC responsiveness.	
3	Regulatory and Human Resource Enablers	Policy and Regulatory Support	RH_1	The government should provide support to speed up the evaluation processes for new pharmaceuticals, medical treatments and healthcare solutions.	Dizon et al. (2017) and Dixit et al. (2019).
		Workforce motivation	RH_2	The motivation for employee involvement in decision-making and corrective measures. Performance incentives allow employees to enhance their dedication and productivity in their work.	Endalamaw, A. et al. (2024)
		Workforce Training and Development	RH_3	The organization must continually learn new skills while building training facilities to adapt to environmental changes and patient needs.	Dixit et al. (2019)
4	Operational and Structural Enablers	Inbound and outbound transportation management	OS_1	Novel approaches to improve final-stage delivery in healthcare supply chains.	Chatterjee, S. et al. (2024)
		Decentralization structure	OS_2	The decentralized business arrangement enables efficient decision-making across all levels of SC which optimizes network responsiveness.	Thomas et al. (2016), Sajid et al. (2016), Bieganska (2022).

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Table 2: Random index

Matrix	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0 5 8	0 9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.58	1.29

2.5 Fuzzy TOPSIS

The FTOPSIS extends the traditional TOPSIS method by integrating fuzzy set theory to address uncertainty in decision-making. This study employs the FTOPSIS methodology consists of multiple steps, which are outlined as follows (Nădăban et al., 2016):
Step 1: Create a decision matrix.
Step 2: A weight matrix represents the evaluation of criteria importance based on FAHP decision making.
Step 3: All numeric fuzzy evaluation matrices are consolidated into one matrix.
Step 4: Develop the normalized decision matrix.
Step 5: Develop the weighted normalized decision matrix.
Step 6: Determination of the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).
Step 7: The Euclidean distance between each alternative and ideal solutions where d_i^+ shows the distance from FPIS while d_i^- represents the distance from FNIS.
Step 8: Calculation of closeness coefficient (CC_i)
Step 9: Rank the enablers:
The best enabler is the one with the highest closeness coefficient.

2.6 Integrated FAHP-FTOPSIS Approach

The research design combines FAHP and FTOPSIS analysis which extract benefits from both methodologies. The FAHP technique evaluates and assigns weights to the evaluation criteria that FTOPSIS will utilize. The integration merges FAHP hierarchical decomposition and pairwise comparison features with FTOPSIS ability to determine solutions closest to the ideal version while being farthest from the negative version.

The research approach illustrated in Figure 1 implements both FAHP and FTOPSIS evaluation methods as shown in this study.

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3. Results Analysis of FAHP and FTOPSIS Approach

3.1 Results of Fuzzy AHP

3.1.1 Weights of Main Enabler Categories

The first step in the FAHP analysis involved determining the relative importance of the four main enabler categories: Technology and Information-Centric Enablers (TI), Integration and Collaboration Enablers (IC), Regulatory and Human Resource Enablers (RH), and Operational and Structural Enablers (OS). Table 3 presents the fuzzy pairwise comparison matrix for these categories based on the aggregated expert judgments.

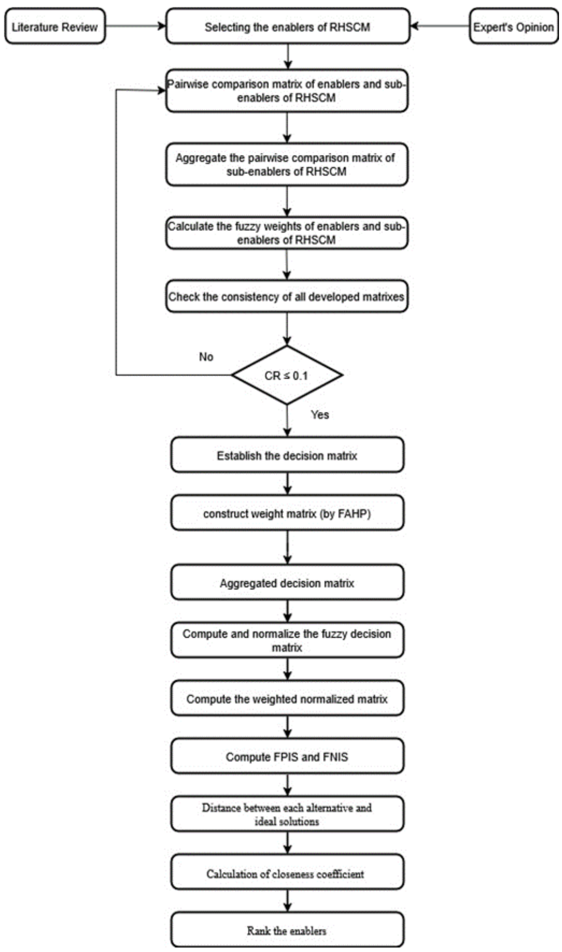

Fig. 1: Research Methodology Framework

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Table 3: Fuzzy Pairwise Comparison Matrix for Main Enabler Categories

	TI	**IC**	**RH**	**OS**
TI	(1.00, 1.00, 1.00)	(2.21, 3.15, 4.12)	(3.42, 4.36, 5.27)	(4.18, 5.24, 6.17)
IC	(0.24, 0.32, 0.45)	(1.00, 1.00, 1.00)	(2.35, 3.28, 4.17)	(3.27, 4.21, 5.18)
RH	(0.19, 0.23, 0.29)	(0.24, 0.30, 0.43)	(1.00, 1.00, 1.00)	(1.89, 2.75, 3.65)
OS	(0.16, 0.19, 0.24)	(0.19, 0.24, 0.31)	(0.27, 0.36, 0.53)	(1.00, 1.00, 1.00)

The fuzzy synthetic extent values for each category were calculated following the extent analysis method. Table 4 presents these values, the degree of possibility, and the final normalized weights.

Table 4: Fuzzy Synthetic Extent Values and Weights of Main Enabler Categories

Category	**Fuzzy Synthetic Extent Value**	**Minimum Degree of Possibility**	**Normalized Weight**
TI	(0.36, 0.48, 0.63)	1.00	0.42
IC	(0.23, 0.31, 0.41)	0.71	0.30
RH	(0.11, 0.15, 0.20)	0.37	0.16
OS	(0.06, 0.08, 0.11)	0.29	0.12

The results indicate that Technology and Information-Centric Enablers (TI) are considered the most important category (weight = 0.42), followed by Integration and Collaboration Enablers (IC) (weight = 0.30), Regulatory and Human Resource Enablers (RH) (weight = 0.16), and Operational and Structural Enablers (OS) (weight = 0.12).

3.1.2 Weights of Sub-Enablers

The next step involved determining the relative importance of the sub-enablers within each main category. Tables 5-8 present the fuzzy pairwise comparison matrices for the sub-enablers within each category.

Table 5: Fuzzy Pairwise Comparison Matrix for Technology and Information-Centric Sub-Enablers

	TI_1	**TI_2**	**TI_3**	**TI_4**
TI_1	(1.00, 1.00, 1.00)	(0.32, 0.42, 0.54)	(0.23, 0.31, 0.42)	(0.19, 0.25, 0.34)
TI_2	(1.85, 2.38, 3.13)	(1.00, 1.00, 1.00)	(0.42, 0.53, 0.68)	(0.31, 0.42, 0.56)
TI_3	(2.38, 3.23, 4.35)	(1.47, 1.89, 2.38)	(1.00, 1.00, 1.00)	(0.68, 0.87, 1.12)

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TI_4	(2.94, 4.00, 5.26)	(1.79, 2.38, 3.23)	(0.89, 1.15, 1.47)	(1.00, 1.00, 1.00)

Table 6: Fuzzy Pairwise Comparison Matrix for Integration and Collaboration Sub-Enablers

	IC_1	**IC_2**	**IC_3**
IC_1	(1.00, 1.00, 1.00)	(1.21, 1.68, 2.23)	(1.89, 2.45, 3.15)
IC_2	(0.45, 0.60, 0.83)	(1.00, 1.00, 1.00)	(1.58, 2.12, 2.78)
IC_3	(0.32, 0.41, 0.53)	(0.36, 0.47, 0.63)	(1.00, 1.00, 1.00)

Table 7: Fuzzy Pairwise Comparison Matrix for Regulatory and Human Resource Sub-Enablers

	RH_1	**RH_2**	**RH_3**
RH_1	(1.00, 1.00, 1.00)	(1.68, 2.34, 3.12)	(1.35, 1.87, 2.45)
RH_2	(0.32, 0.43, 0.60)	(1.00, 1.00, 1.00)	(0.68, 0.87, 1.12)
RH_3	(0.41, 0.53, 0.74)	(0.89, 1.15, 1.47)	(1.00, 1.00, 1.00)

Table 8: Fuzzy Pairwise Comparison Matrix for Operational and Structural Sub-Enablers

	OS_1	**OS_2**
OS_1	(1.00, 1.00, 1.00)	(1.68, 2.25, 2.94)
OS_2	(0.34, 0.44, 0.60)	(1.00, 1.00, 1.00)

Following the same procedure as for the main categories, the weights of the sub-enablers within each category were calculated. Table 9 presents the local and global weights of all sub-enablers.

Table 9: Local and Global Weights of Sub-Enablers

Category	**Category Weight**	**Sub-Enabler**	**Local Weight**	**Global Weight**	**Rank**
		TI_1	0.10	0.042	8

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TI	0.42	TI_2	0.20	0.084	5
		TI_3	0.32	0.134	2
		TI_4	0.38	0.160	1
IC	0.30	IC_1	0.48	0.144	1
		IC_2	0.35	0.105	2
		IC_3	0.17	0.051	3
RH	0.16	RH_1	0.52	0.083	1
		RH_2	0.19	0.030	3
		RH_3	0.29	0.046	2
OS	0.12	OS_1	0.69	0.083	1
		OS_2	0.31	0.037	2

The global weights were calculated by multiplying the local weights of the sub-enablers by the weights of their respective main categories. Based on these global weights, the top three sub-enablers are Information transparency (TI_4) with a weight of 0.160, Real-time monitoring/Supply Chain Visibility (TI_3) with a weight of 0.134, and Strategic commitment and resource availability (IC_1) with a weight of 0.144.

3.2 Results of Fuzzy TOPSIS

The Fuzzy TOPSIS analysis was used to rank the sub-enablers based on their performance against five evaluation criteria: effectiveness, feasibility, sustainability, cost-efficiency, and adaptability. The weights of these criteria were determined through expert judgment. Table 10 presents the criteria weights used in the FTOPSIS analysis.

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Table 10: Weights of Evaluation Criteria

Criterion	Weight
Effectiveness	0.28
Feasibility	0.22
Sustainability	0.18
Cost-efficiency	0.15
Adaptability	0.17

Table 11 presents the aggregated fuzzy decision matrix, where each element represents the rating of a sub-enabler with respect to a criterion.

Table 11: Aggregated Fuzzy Decision Matrix

Sub-Enabler	Effectiveness	Feasibility	Sustainability	Cost-efficiency	Adaptability
TI_1	(4.2, 5.3, 6.2)	(3.7, 4.8, 5.8)	(4.0, 5.1, 6.1)	(2.8, 3.7, 4.7)	(4.1, 5.2, 6.2)
TI_2	(5.3, 6.3, 6.8)	(4.2, 5.2, 6.2)	(4.6, 5.6, 6.5)	(3.8, 4.8, 5.8)	(4.7, 5.7, 6.6)
TI_3	(5.8, 6.6, 6.9)	(4.5, 5.5, 6.4)	(5.1, 6.1, 6.7)	(3.6, 4.6, 5.6)	(5.2, 6.2, 6.8)
TI_4	(6.1, 6.8, 7.0)	(5.0, 6.0, 6.7)	(5.4, 6.4, 6.9)	(4.5, 5.5, 6.4)	(5.5, 6.5, 6.9)
IC_1	(5.7, 6.5, 6.9)	(5.2, 6.2, 6.8)	(4.8, 5.8, 6.6)	(4.2, 5.2, 6.2)	(5.1, 6.1, 6.7)
IC_2	(5.2, 6.2, 6.8)	(4.8, 5.8, 6.5)	(4.6, 5.6, 6.5)	(4.0, 5.0, 6.0)	(4.8, 5.8, 6.6)
IC_3	(4.8, 5.8, 6.6)	(4.5, 5.5, 6.4)	(4.3, 5.3, 6.3)	(3.8, 4.8, 5.8)	(4.6, 5.6, 6.5)
RH_1	(5.1, 6.1, 6.7)	(4.3, 5.3, 6.3)	(5.0, 6.0, 6.7)	(4.6, 5.6, 6.5)	(4.2, 5.2, 6.2)
RH_2	(4.5, 5.5, 6.4)	(4.7, 5.7, 6.5)	(4.2, 5.2, 6.2)	(4.8, 5.8, 6.6)	(4.4, 5.4, 6.4)
RH_3	(4.7, 5.7, 6.5)	(4.9, 5.9, 6.6)	(4.5, 5.5, 6.4)	(4.3, 5.3, 6.3)	(4.6, 5.6, 6.5)
OS_1	(5.0, 6.0, 6.7)	(5.1, 6.1, 6.7)	(4.8, 5.8, 6.6)	(4.5, 5.5, 6.4)	(4.9, 5.9, 6.6)

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OS_2	(4.6, 5.6, 6.5)	(4.8, 5.8, 6.6)	(4.5, 5.5, 6.4)	(4.7, 5.7, 6.5)	(5.0, 6.0, 6.7)

The FTOPSIS methodology required calculation of normalized decision matrices as well as weighted normalized decision matrices. Each criterion received a determination of their fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS). Researchers calculated the distance between each sub-enabler and the FPIS and the FNIS before determining its closeness coefficient. Table 12 presents the closeness coefficients and rankings of the sub-enablers.

Table 12: Closeness Coefficients and Rankings of Sub-Enablers

Sub-Enabler	**Distance to FPIS**	**Distance to FNIS**	**Closeness Coefficient**	**Rank**
TI_1	3.145	1.235	0.282	12
TI_2	2.587	1.843	0.416	7
TI_3	2.064	2.366	0.534	2
TI_4	1.712	2.718	0.613	1
IC_1	1.856	2.574	0.581	3
IC_2	2.215	2.215	0.500	4
IC_3	2.485	1.945	0.439	6
RH_1	2.248	2.182	0.493	5
RH_2	2.634	1.796	0.405	9
RH_3	2.541	1.889	0.426	8

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OS_1	2.354	2.07 6	0.469	7
OS_2	2.625	1.80 5	0.408	10

Based on the closeness coefficients, the top three sub-enablers are:

1. Information transparency (TI_4) with a closeness coefficient of 0.613
2. Real-time monitoring/Supply Chain Visibility (TI_3) with a closeness coefficient of 0.534
3. Strategic commitment and resource availability (IC_1) with a closeness coefficient of 0.581

FTOPSIS results confirm the earlier FAHP findings about three sub-enablers serving as essential elements for strengthening healthcare supply chain responsiveness in India.

3.3 Comparative Analysis of FAHP and FTOPSIS Results

Table 13 presents a comparative analysis of the rankings obtained from the FAHP and FTOPSIS methods.

Table 13: Comparative Analysis of FAHP and FTOPSIS Rankings

Sub-Enabler	**FAHP Rank**	**FTOPSIS Rank**	**Average Rank**
TI_1	8	12	10
TI_2	5	7	6
TI_3	2	2	2
TI_4	1	1	1
IC_1	3	3	3
IC_2	4	4	4

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IC_3	7	6	6.5
RH_1	6	5	5.5
RH_2	11	9	10
RH_3	8	8	8
OS_1	6	7	6.5
OS_2	10	10	10

The comparison shows that both methods closely match their positioning order. The two enablers of information transparency (TI_4) and real-time monitoring/supply chain visibility (TI_3) appear as strategies. The third and fourth most important enablers as per the results consistently demonstrate strategic commitment and resource availability (IC_1) together with healthcare partner collaboration (IC_2). Several verification methods have shown identical enabler rankings which supports the result accuracy and builds trust in enabler priority choices. The rankings obtained from both FAHP and FTOPSIS methodologies appear in Figure 2.

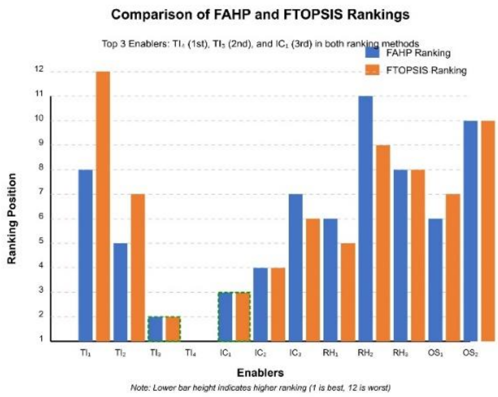

Fig. 2: Comparison of FAHP and FTOPSIS Rankings

4 Discussion on Findings

This research explores the ranking of enablers to enhance India's healthcare supply chain responsiveness through valuable findings. The section analyzes essential results and their repercussions for healthcare administrators in addition to policymakers along with supply chain managers.

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4.1 Technology and Information-Centric Enablers

The FAHP analysis shows that Technology and Information-Centric Enablers (TI) constitute the most important segment to enhance healthcare supply chain responsiveness in India. Both Information transparency (TI_4) and Real-time monitoring/Supply Chain Visibility (TI_3) stood as the leading enablers under this category in agreement between FAHP and FTOPSIS assessments. TI_4 represents the practice of open information sharing across supply chain partners where they exchange inventory metrics together with supply forecasting data and manufacturing operations plans (Wang, Z. et al., 2024). Transparency in healthcare settings builds trust between stakeholders and improves collective activities coordination. Information transparency receives top priority because established that transparent healthcare supply chains cut down the bullwhip effect as well as enhance overall supply chain responsiveness. Real-time product tracking within the supply chain needs primarily in healthcare settings because it safeguards both product quality and delivery speed and ensures medical products remain genuine. Real-time visibility stands as a crucial requirement due to the supply disruptions during COVID-19 which happened because companies lacked clear monitoring (Dey, S. (2023). The FAHP analysis positions Data Quality and Sharing (TI_2) at rank number five while FTOPSIS lists it as seventh. TI_2 offers vital support to healthcare supply chain responsiveness although it does not rank among the initial three critical factors. The ability to process and distribute quality data stands as the basics for real-time tracking and transparent information systems (Biswas, T. R. et al., 2024). Among the five factors TI_1 stands as the lowest-ranked element according to both FAHP (8th) and FTOPSIS (12th). The study implies that technological infrastructure maintains importance although attention must remain focused on harnessing technology to boost information circulation instead of concentrating on tech tools.

4.2 Integration and Collaboration Enablers

The second most crucial enabler discovered during the FAHP analysis was Integration and Collaboration Enablers (IC). The strategic commitment to resources availability (IC_1) emerges as the third most essential factor according to the FAHP analysis within this category. Strategic commitment and resource availability (IC_1) refers to the dedication of organizational leadership towards supply chain improvement and allocating necessary resources for implementation of responsiveness. Leadership commitment functions as an essential element for success in supply chain transformation initiatives (Prabhu, M. et al. 2023). The results from both FAHP and FTOPSIS position Collaboration with Healthcare Partners (IC_2) at rank number four. The enabler focuses on building cooperative relationships between various healthcare stakeholders such as suppliers and distributors and both hospitals and government bodies. Partnerships emerge as essential in the Indian healthcare industry since system

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fragmentation requires powerful alliances for effective product and information movement. Customer and supplier integration (IC_3) demonstrates a lower position in the ranking (7th in FAHP and 6th in FTOPSIS). The results indicate that ecosystem-wide collaboration stands above supplier-customer linkages as the primary factor for success in the Indian healthcare sector.

4.3 Regulatory and Human Resource Enablers

Regulatory and Human Resource Enablers (RH) rank third among the main categories, in the FAHP analysis. Policy and Regulatory Support (RH_1) stands as the most vital sub-enabler within this classification according to both FAHP (6th) and FTOPSIS (5th) analysis. The implementation of facilitating policies and regulations under Policy and Regulatory Support (RH_1) creates conditions for effective supply chain operations. The high ranking of this enabler demonstrates how regulatory frameworks substantially influence Indian healthcare supply chain operations. The research analyses show Workforce Training and Development (RH_3) and Workforce motivation (RH_2) as ranking lower than the other factors. Human resource elements play an important role but generate smaller immediate effects on supply chain responsiveness compared to technological and integration elements together with regulatory elements.

4.4 Operational and Structural Enablers

Operational and Structural Enablers (OS) rank fourth among the main categories in the FAHP analysis. Studies identify Inbound and outbound transportation management (OS_1) as the leading sub-enabler in this category by ranking 6th using FAHP and 7th using FTOPSIS. The efficient management of product delivery operations through inbound and outbound transportation activities represents inbound and outbound transportation management (OS_1) .The moderate position of logistics as an enabler reveals that supply chain operations retain essential importance yet information flow together with collaborative partnerships have a stronger influence on responsiveness. The results from both analyses show Decentralization structure (OS_2) holds a low ranking position. The low ranking of organizational structure in both analyses indicates that other supply chain enablers have stronger impacts on system responsiveness in the Indian healthcare environment.

4.5 Practical Implication

This research study generates multiple implications for healthcare administrators alongside policymakers and supply chain managers operating within the Indian healthcare system.

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4.5.1 Focus on information flow

Organizations must invest in systems that improve information flow throughout their supply chain based on results that show high value in information transparency and real-time visibility. The organization needs to develop visibility platforms while setting protocols for information sharing with their supply chain partners and implementing dashboard sharing initiatives.

4.5.2 Leadership commitment

The requirements of strategic commitment with available resources demonstrate why leadership support combined with continued financial backing is necessary for supply chain enhancement programs. Organizations must establish supply chain responsiveness as a key strategic priority which must gain attention from their top management team.

4.5.3 Collaborative approach

Supply chain management requires collaborative approaches because healthcare partnerships hold a high position in the survey results. Organizations need to develop solid stakeholder ties within the healthcare environment through strategic cooperative systems that combine teamwork protocols and unified measurement systems.

4.5.4 Supportive regulatory framework

Policy and regulatory support needs attention from officials to create enabling frameworks which promote instead of burden responsive supply chain procedures. Standardized product codes need to be introduced while approval systems should be optimized and regulatory standards need to be made consistent between different regional territories.

5. Conclusion

An integrated Fuzzy AHP and Fuzzy TOPSIS method was used to establish and rank the enablers of responsive healthcare supply chain management in India during this research. The research exhibits that Information transparency (TI_4), Real-time monitoring/Supply Chain Visibility (TI_3) and Strategic commitment and resource availability (IC_1) serve as the leading enablers for boosting Indian healthcare supply chain responsiveness. The research provides substantial value to academic studies and practical usage applications. The model presents a comprehensive system for both evaluation and priority-setting of elements which enable HSCM responsiveness within India. The study uses an integrated MCDM method which efficiently handles unclear information and personal judgments found in expert decision-making processes. The study creates specific guidelines which supply chain managers

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together with healthcare administrators and policymakers can utilize to develop strategic decisions about hospital supply chain implementations.

The conducted research demonstrates how effective supply chain visibility together with information data sharing plays an essential role in developing healthcare supply chain responsiveness. The research emphasizes how information visibility and communication strength fuel responsive healthcare supply system development. Research evidence shows that transparent information systems with real-time capabilities matter more than mere adoption of modern technology. Additionally, the results emphasize the significance of leadership commitment and collaborative relationships in driving supply chain responsiveness.

5.1 Limitations and Future Research Directions

The study contains various limitations that identify possibilities for future research. Uncertainties impact this study by using expert judgments even when fuzzy methods are applied to manage uncertainty. The research conducts its analysis within an Indian healthcare framework thus the results might not directly transfer to healthcare organizations operating under different systems and challenges internationally. Nationwide analysis between different countries can disclose essential variables influencing health service organizations to prioritize particular enablers.

Research should explore how the enablers relate to each other by applying analytical tools like DEMATEL and interpretive structural modelling. The assessment of enabler prioritizing patterns should be conducted through longitudinal research during stages of disruption and policy change. Analyses of effective supply chain implementation projects provide essential learning opportunities about how organizations boost responsiveness by handling these enablers. Supply chains in healthcare require responsiveness because it sustains medical products and services accessibility particularly in constrained environments such as India.

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