Modelling the Key Performance Indicators of Responsive Healthcare Supply Chain Management in India - A Fuzzy ANP and Fuzzy DEMATEL Approach

Shashank Srivastava[1]*, Dixit Garg[2]
[1]Department of Mechanical Engineering, NIT Kurukshetra, Haryana, and Department of Mechanical Engineering, GLA University Mathura (U.P.)
[2]Department of Mechanical Engineering, NIT Kurukshetra, Haryana

Abstract

The purpose of the study is to design a to model key performance indicators (KPIs) of responsive healthcare supply chain management in India through integrated Fuzzy Analytic Network Process (FANP) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL) approach.14 KPIs organized into four clusters: Emergency Response & Time-Critical Operations, Supply Chain Agility & Flexibility, Digital Integration & Visibility, and Quality Assurance & Compliance. The study involved use of expert judgments involving healthcare supply chain experts in India to form causal relationships and assign priorities weights. The FDEMATEL analysis showed Digital Integration & Visibility was the most influential cluster on the other clusters with the Emergency Response & Time-Critical Operations being the most affected cluster. The FANP outcomes revealed Emergency Response Time, Real-time Inventory Visibility Rate, and Supply Chain Flexibility Index as the most significant KPIs with weight of 0.142, 0.138, and 0.125 correspondingly. It is restricted to the Indian healthcare environment, and is based on the expert opinions. Future studies may confirm the findings with empirical research in various geographic locations. The given model helps healthcare organizations and policymakers prioritize resources, enhance the supply chain responsiveness, and develop better crisis preparedness capacities.

Keywords: Healthcare supply chain, Responsiveness, Key performance indicators, Fuzzy DEMATEL, Fuzzy ANP.

1. Introduction

The healthcare supply chains (HSC) are one of the most multifaceted and mission-critical logistical systems in the world, as they are a backbone in making sure that medical supplies, pharmaceutical products, and equipment are delivered to healthcare organizations on time (Kalaria, C et al., 2023). The recent COVID-19 has fundamentally revealed the weaknesses and inefficiencies of the global healthcare supply chains requiring a paradigm shift, which necessitates more resilient and responsive management strategies (Araujo, R.et al., 2023). The pandemic has had its most devastating effects felt in the developing economies and countries like India have experienced hard times in maintaining key flows of medical supplies in times of crisis. The crisis exposed the basic flaws in the coordination of supply chains, and the disaggregated nature of healthcare systems failed to offer patients alternative pathways through which they could receive access to life-saving medical supplies (Chen, Z. S. et al., 2024). Performance measurement has become a crucial requirement in healthcare organizations that are working towards being service-oriented, efficient and enhancing both clinical and non-clinical outcomes in a competitive healthcare environment (Fallahnezhad et al., 2024). The notion of supply chain responsiveness has acquired the ultimate significance in the context of modern literature, mainly in the area of crisis management where the ability to quickly adapt proves to define organizational survival (Badwan, N. 2025). In the modern dynamic contemporary perception of ever-unpredictable turns and steep market competition the supply chains are taking ever more concentrated interests in conducting the responsive strategies and at the lowest operational costs (Bathaei, A. 2024). Responsiveness of healthcare supply chain includes the organizational competence to respond rapidly to changing demand trends, supply crises and shocks, and surprises and to comply with quality standards and cost-effectiveness factors (Mishra, N. K. et al., 2025). The specifics of the healthcare industry, such as life-saving properties of items, regulatory needs, uncertainty, and unpredictability of demand, add more complexity than those of regular supply chains (Jia, F. et al., 2025).

According to a study by Munir M. et al. (2022), the potential to improve resilience and responsiveness in the supply chain during the COVID-19 was examined, with the researcher finding the improvisation, anticipation, and data analytics capabilities are essential enablers of crisis response effectiveness. The research, revealed that companies with highly developed improvisation skills prevailed with 34 percent quicker response times to supply shocks as compared to companies with low levels of improvisation. The study established that the data analytics capability mediates the associations amid anticipation and responsiveness (i.e., the potential of organizational responsiveness grows multifold with technological infrastructure). Spieske A.et al. (2022) explored the resilience of the European healthcare supply chain under the COVID-19 crisis and identified seven hot propositions that address relations between management of the resource dependencies, buffering and bridging as a complex of the relations. The research established that collaborative planning mechanisms and supplier diversification had a profound positive effect towards increasing the organizational responsiveness to unforeseen changes in demand. Fallahnezhad et al. (2024) produced the largest cumulative systematic review of hospital supply chain KPIs by reviewing nineteen studies in seven primary databases identifying sixty-four performance indicators grouped on financial (thirty-seven indicators), managerial (fifteen indicators), and clinical (twelve indicators) levels. In their findings, it was observed that the current performance measurement practice is characterized by a large concentration of financial indicators, with responsiveness-oriented metrics being a rare commodity. Burlea-Schiopoiu and Ferhati (2020) analyzed managerial implications of healthcare KPIs in pandemic crisis situations in Algeria and found out that four clusters of KPIs can be significantly associated with the effectiveness of managing the crisis. Their cross-sectional study of medical workers showed that the interrelation of human factors, technology, and medication is a determinant element in minimizing the burden of the healthcare system during emergency times. The research has found out that an organization with integrated KPI clusters tracked had a 19 percent improvement in performance on crisis response over organizations with isolated metrics. Fallahnezhad, M. et al. (2024) designed an extended framework of KPIs in allied healthcare educational institutions and this gives an insight into the general healthcare supply chain settings. In their study, they found important performance dimensions such as operational efficiency, quality assurance, stakeholder satisfaction, and resource utilization, and the interdependence of these dimensions has a great impact on performance of organization as a whole. Nabovati et al. (2023) explored hospital management dashboards KPI on national scales, and their findings showed that managers prefer real-time access and a composite set of performance indicators. Their investigation of the opinions of hospital managers showed that companies following the use of comprehensive KPI dashboards obtain 22% faster decision-making rate and 15% more effective resource distribution.

Pamucar et al. (2022) proposed a new fuzzy rough decision-making system of selecting suppliers in healthcare supply chain management under COVID-19, showing that fuzzy techniques in this case offer a better treatment in uncertainty than classic techniques. Their use in medical settings showed higher accuracy and lowered chances of selection. Goncu, K. K. et al. (2022) generated a Fuzzy DEMATEL-ANP process that prioritizes activities in enterprise architecture by arranging methodological underpinnings that can be utilised in healthcare supply chain situations. Their study found out that hybrid fuzzy methods are more thorough in giving insights into complex organizational relationships than the single approaches, and better in ranking priorities and identifying causal relationship. Chen et al. (2019) also developed MCDM-based DEMATEL-ANP methods of project risk management solutions, which can be used in designing the measurement of healthcare supply chain performance. Their study found out that integrated fuzzy methods provide a better management of interdependencies of performance criteria than traditional methods, keeping computational cost low. The literature review offers numerous gaps that this study identifies and fills.

1. There is a remarkable amount of research on supply chain responsiveness in general and very limited research on healthcare supply chain responsiveness with respect to crisis situation, especially in a developing economy such as India.

2. Current KPI systems on healthcare supply chains are frequently centered on efficiency and financial aspects, lack relevance in the aspect of effectiveness of responsiveness in crisis situations.
3. Fuzzy MCDM approaches have been used separately on different supply chain issues, and there is only scarce research that unites FDEMATEL and FANP towards modeling KPI in healthcare supply chains.
4. Most of the current studies of performance supply chain in healthcare are done within the context of the developed countries and neglect issues departing distinctively from emerging healthcare systems.

The specific objectives of this research are:

1. Build a KPI framework particular to the needs of responsive healthcare supply chain management, tailored to the India healthcare environment through inclusion of 14 performance measures in four strategic categories (Emergency Response & Time-Critical Operations, Supply Chain Agility & Flexibility, Digital Integration & Visibility, Qualified Assurance and Compliance).
2. In order to implement a coherent Fuzzy DEMATEL and Fuzzy ANP approach to model complex interdependencies and prioritize KPIs in the context of uncertainty and imprecision that prevails in the healthcare supply chain setting, overcoming the shortcoming of current methods that consider performance indicators independently.
3. To interpret the causal links among health industry supply chain performance indicators and categorize them as cause or effect in order to relate the system dynamics, and determine the leverage points to begin a systematic improvement strategy.
4. To create a three-level strategy of prioritization providing evidence-based guidelines to healthcare managers when performing resource allocation and performance improvement endeavors, filling the chasm between scholarly studies and actual application.

The conducted studies have a number of important new contributions, which makes it unique on the existing literature and moves the research area of healthcare supply chain management in several dimensions, including:

1. It is the first integration of the Fuzzy DEMATEL and Fuzzy ANP techniques to the specific supply chain KPI modeling in healthcare setting, which introduces a new analytical model that covers interdependencies in a complex manner, and uncertainty in measuring healthcare performance.
2. New three-level prioritization framework is the first structured method of KPIs in healthcare supply chains prioritization which combines cause-effect relationships with the prioritization of performance in performance weights.
3. First general theoretical model fills an important gap in the theory of supply chains, in that it identifies and presents the model of characteristics that are distinctive in life-critical services delivery systems.
4. New cause-effect classification is the first empirical evidence of the existence of cause-effect relations amidst wholesome healthcare supply chain performance indicator.
5. Best-practice strategic information with short-term implementation implications available to the healthcare practitioner and policymaker. The study provides the most systematic way of managing healthcare supply chain responsiveness that can be applied by healthcare organizations in a direct way.

This research can make significant contributions to the alleviation of urgent practical problems associated with the management of the health care supply chain. The framework supplies healthcare organizations with systematic methods of making supply chains more responsive and in benefiting national policy goals of health security and self-sufficiency. The study provides a contribution to the incipient concept of healthcare 4.0 by showing the opportunities to strategically use digital technologies to amplify the level of responsive performance in circumstances of resource limitation. The anticipated effect is an immediate contribution to practice by giving healthcare organizations insight into how to better their supply chain, theory contribution in the area of healthcare operations management and also assistance in policy-making to the development of healthcare supply chain initiatives.

The remainder of this manuscript is organized as follows: Section 2 describes the materials and methodology employed in this study. Section 3 presents comprehensive results of FDEMATEL and FANP applications. Section 4 discusses the findings of this research. Section 5 theoretical and practical implications of the findings. Section 6 conclusions. Section 8 concludes the research with limitations and directions for future research.

2. Materials and Methodology

2.1 Research Design

In this research, the quantitative approach to research that relies on a cross-sectional survey research method and complex tools of multi-criteria decision-making is chosen. The research design used is according to the guidelines of research on healthcare supply chain and it applies expert panel consultation that incorporates structured quantitative approach based on fuzzy MCDM techniques.

2.2 Identification of KPI of RHSCM

The development of KPI of RHSCM was conducted in a multi-stage systematic process. An extensive literature search based on the most important academic databases allowed finding important KPIs in healthcare supply chain studies published in 2020-2024. The definition of the initial list of KPIs was complemented by the consultation of five healthcare supply chain professionals via structured interviews. The various KPI of RHSCM is represented in Table 1.

2.3 Expert Panel Selection & Data Collection

The expert panel consists of 18 professionals who are chosen using stringent criteria such as having a minimum of 10 years experience in the healthcare supply chain, exceptional experience and exposure in crisis management, and representation in terms of geographical mix in India. In the panel we have healthcare supply chain managers (6), procurement specialists (4), IT professionals (3), academic researchers (3), and government advisors (2).

Information gathering took a three-phased pattern:

Phase 1: Validation of the framework by conducting structured interviews with members of the panel of experts individually to discuss the definitions of the KPIs and evaluate applicability.

Phase 2: In the case of FDEMATEL data gathering, linguistic variable data would be changed to triangular fuzzy numbers of five levels of influence that range between Very Low (0,0,0.25) and Very High (0.75,1.0,1.0).

Phase 3: The FANP Data collection method that would have been used is pairwise comparison matrices that uses Saaty 1-9 scale to triangular fuzzy numbers in order to solve the uncertainty in judgments of the experts.

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

S.N.	Cluster	KPI	Code	Brief Description	Sources
1	Emergency Response & Time-Critical Operations	Emergency Response Time	K1	The period between the recognition of a critical healthcare supply requirement into the commencement of the response effort.	Spieske, A. et al. (2022)
2		Critical Supply Stockout Frequency	K2	The number of stockouts of vital medical supplies, medications and equipment which are deemed an important part of patient care.	Senna, P. et al. (2023)
3		Emergency Inventory Activation Time	K3	Time it takes to bring emergency inventory reserves into action in the case of disruption of regular supply channels.	Li, X. et al. (2023)

4		Crisis Communication Response Time	K4	The duration used in conveying important supply chain information to stakeholders in case of an emergency.	Scala, B. et al. (2021)
5	**Supply Chain Agility & Flexibility**	Supply Chain Flexibility Index	K5	A combination measure of the flexibility of the supply chain to suit demands, supply and operating relations changes.	Dahinine, B. et al. (2024)
6		Vendor Diversification Index	K6	An index of supply base diversity within geographic, company size and Supply capabilities as an effort of minimizing dependency risk.	Sharma, A. et al. (2020)
7		Supplier Response Time	K7	The typical period suppliers require to respond to an urgent request of quotation, order alterations, or emergency supply demands.	Tortorella, G. L. et al. (2024)
8		Multi-Modal Transportation Utilization	K8	The degree to which the supply chain combine various transportation services (road, rail, air, water) to maximise options in terms of speed and reliability of delivery.	Christopher, M. et al. (2017)
9	**Digital Integration & Visibility**	Real-time Inventory Visibility Rate	K9	The percentage of inventory items of which the current quantity, location and status across the supply network is known and in real-time.	Saha, E. et al. (2024)
10		Digital Integration Score	K10	A digitalization level measure that is a sum of the digital technology (AI, blockchain, IoT, analytics) degree of integration in the supply chain processes.	Karatas, M. et al. (2022)
11		Demand Forecast Accuracy	K11	The degree in which the forecasted demand is accurate against the actual demand of healthcare supplies and healthcare services.	Frederico, G. F. et al. (2019)
12		Order-to-Delivery Cycle Time	K12	The amount of time passing between the moment an order is placed to the point when it is delivered to the healthcare facility, including all supply chain activities.	Fallahnezhad, M. et al. (2024)
13	**Quality Assurance & Compliance**	Last-Mile Delivery Success Rate	K13	Percent of orders that have been delivered to a healthcare facility successfully during the first delivery attempt, at the right quantities, and condition.	McGuinn, J. N. (2021)
14		Cold Chain Integrity Rate	K14	Proportion of temperature-sensitive products related to the field of medical products (vaccines, biologics, some pharmaceuticals) that have not exceeded required temperature in the supply chain.	Fallahnezhad, M. et al. (2024

2.4 Fuzzy DEMATEL Methodology

The Fuzzy DEMATEL is based on the improved technique of healthcare applications, with the addition of the recent developments in processing of fuzzy numbers and consistency checks.

Step 1: Initial Direct Relation Matrix Construction

Linguistic variable is used to acquire expert appraisals and to transfer it to triangular fuzzy numbers. The first direct relation fuzzy matrix Dijk ... D = [d ij] is derived, and the d ij indicates the degree of direct influence of factor i in factor j, in form of triangular fuzzy numbers d ij = (lij, m ij, u ij).

Step 2: Normalized Direct Relation Matrix

The normalized direct relation fuzzy matrix $\tilde{X}$ is calculated using the equation: $\tilde{X} = \tilde{D}/\max\{\max \sum_{j=1}^{n} u_{ij}, \max \sum_{i=1}^{n} u_{ij}\}$

This normalization ensures that all elements fall within the range [0,1] and maintains consistency across expert evaluations.

Step 3: Total Relation Matrix Computation

The total relation fuzzy matrix $\tilde{T}$ is derived using the fundamental equation: $\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}$

where I represents the identity matrix. This computation captures both direct and indirect relationships among KPIs.

Step 4: Defuzzification and Analysis

To calculate values of prominence (R + C) and relation (R - C), the sum of rows (R) and columns (C) are calculated, allowing achieving information about which factors are the cause and which factors are the effects.

Step 5: Threshold Determination and Network Construction

Relationships beyond the threshold are added in the network structure to undergo further FANP analysis.

2.5 Fuzzy Analytic Network Process Methodology

The FANP implementation is an extension of the improved technique created on complex situation decision making, and recent developments in consistency checking and weighting procedure. The method optimizes the network structure criteria identified in the FDEMATEL analysis whilst keeping performances computationally efficient.

Step 1: Network Structure Development

FANP network structure is built on the nodes of FDEMATEL results, both cluster level and KPI level interdependencies. In this approach, it is ensured that significant causal relationships are incorporated in the network design.

Step 2: Fuzzy Pairwise Comparison Matrices

The both clusters and KPIs within clusters are built on the basis of the pairwise comparison matrices based on the triangular fuzzy numbers used to represent the expert judgments.

Step 3: Consistency Analysis

All the comparison involves the calculation of consistency ratios (CR). The threshold based on $CR < 0.1$ is acceptable and it is kept during the analysis, inconsistent matrices are reviewed and revised by experts.

Step 4: Weight Calculation and Supermatrix Formation

The geometric mean method is used to compute local weights and the center of area defuzzification method is used to bring the values back to crisp values. The supermatrix is created wherein all cluster and KPI relationships identified by using an integrated FDEMATEL-FANP technique would be included.

Step 5: Limit Supermatrix and Final Weights

Limit supermatrix is calculated using multiplication at every iteration till convergence that yields the final weights of priorities of all KPIs.

The research approach illustrated in Figure 1 implements both FDEMATEL-ANP evaluation as shown in this study.

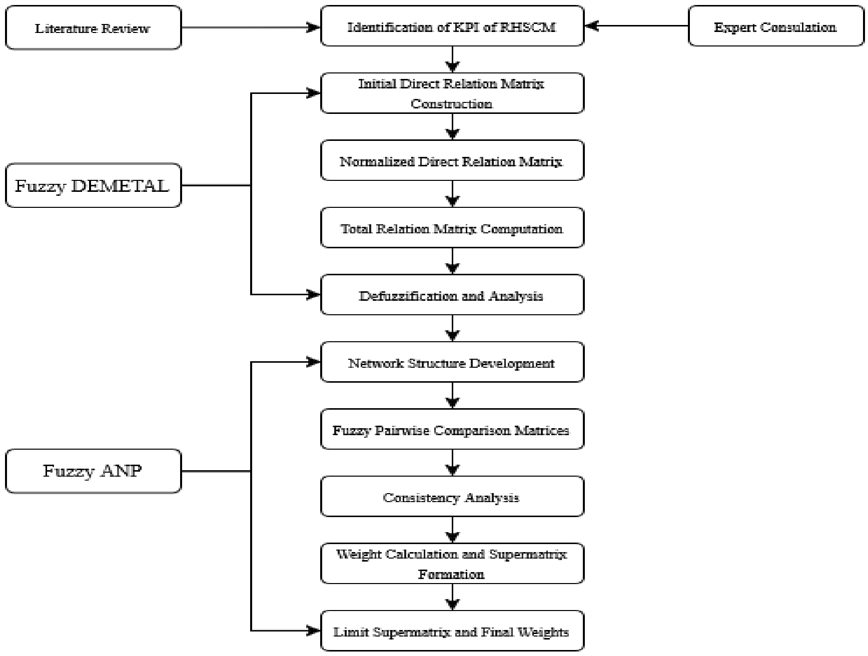

Fig. 1: Integrated Fuzzy DEMATEL-ANP Research Framework for Healthcare Supply Chain KPI Modelling

3. Results and Analysis of Fuzzy DEMATEL and Fuzzy ANP

This section presents the comprehensive analysis results from the integrated Fuzzy DEMATEL and Fuzzy ANP methodology applied to the healthcare supply chain KPI framework.

3.1 Fuzzy DEMATEL Results

The professional assessment procedure led to a complete collection of linguistic analyses of all 14 KPIs in the four groups. Triangular fuzzy numbers were systematically transcribed to linguistic variables. The preprocessing of the data included an aggregation of the expert opinions through a geometric mean method. Consistency analysis was conducted to validate the expert agreement, and an overall coefficient of agreement of 0.823 was observed, which falls above the recommended criterion (0.75) of a reliable group decision in a healthcare context (Rehman, N. et al., 2025).

This is a high degree of agreement which suggests that the experts have been in solid agreement as to ranking the relative importance and interdependencies of indicators of healthcare supply chain performance measures, and this lends credence to results that follow. The original direct influence matrix (D rrñ extending to the 14 rule and basis a total of 196 pairwise evaluations of 15 experts (14×14 matrix). The total influence matrix ($\tilde{T}$) was computed through iterative matrix operations, capturing both direct and indirect relationships among KPIs. Table 2 presents the defuzzified prominence and relation values that form the foundation for causal relationship analysis.

Table 2: Fuzzy DEMATEL Results - Prominence and Relation Analysis

KPI	Description	R+C	R-C	Classification	Influence Level
K1	Emergency Response Time	8.924	0.847	Cause	Very High
K5	Supply Chain Flexibility Index	8.567	0.623	Cause	Very High
K9	Real-time Inventory Visibility Rate	8.156	0.534	Cause	High
K10	Digital Integration Score	7.891	0.423	Cause	High

K2	Critical Supply Stockout Frequency	7.658	-0.234	Effect	High
K6	Vendor Diversification Index	7.123	0.298	Cause	Moderate
K3	Emergency Inventory Activation Time	6.891	0.156	Cause	Moderate
K7	Supplier Response Time	6.789	-0.167	Effect	Moderate
K11	Demand Forecast Accuracy	6.567	-0.145	Effect	Moderate
K4	Crisis Communication Response Time	6.234	-0.412	Effect	Moderate
K12	Order-to-Delivery Cycle Time	6.234	-0.234	Effect	Moderate
K13	Last-Mile Delivery Success Rate	5.789	-0.189	Effect	Low
K8	Multi-Modal Transportation Utilization	5.432	-0.298	Effect	Low
K14	Cold Chain Integrity Rate	5.123	-0.167	Effect	Low

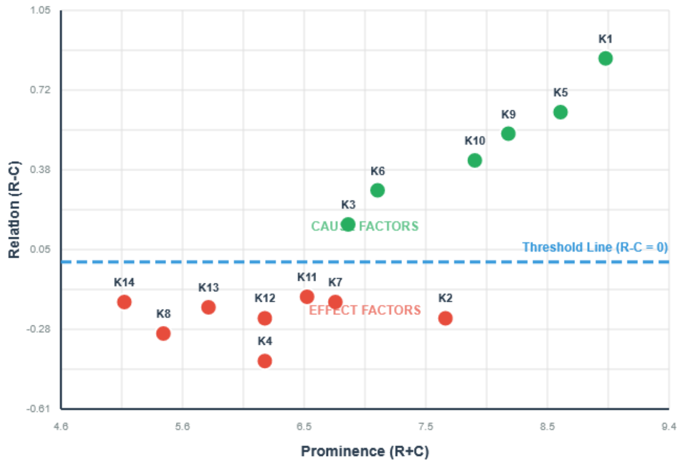

Fig 2. Causal Effect Diagram of KPI

Six KPIs of causes (K1, K3, K5, K6, K9, K10) that are main drivers having a substantial impact on other performance aspects and eight KPIs of effects (K2, K4, K7, K8, K11, K12, K13, K14) implying responsiveness to change of driving factors were identified in the analysis.

3.2 Fuzzy ANP Analysis Results

The network form of FANP was designed using the relationships established by the DEMATEL relationships to achieve a complete decision network where both, hierarchical and lateral KPI interdependencies and clusters are discovered. The structure of network included 14 decision nodes (KPIs) in 4 clusters, which were determined with DEMATEL threshold analysis. The structured interview were administered based on Saaty 9-level scale to obtain expert opinions to conduct pairwise comparisons later transformed into triangular fuzzy numbers that reflect lexical uncertainty. A 31 pair-wise comparisons matrices were generated, with 4 at the cluster-level and 27 within-clusters matrices in view of KPI comparison. The method of consistency analysis was strictly applied to all comparison matrices by checking consistency ratio (CR). The findings exhibited strong reliability whereby all the matrices had CR less than 0.10 and the average CR was 0.067. Unweighted supermatrix: unweighted supermatrix was formed by merging the local priority vectors of all individual matrices of pairwise comparison matrices so that a complete image of interdependencies in the healthcare supply chain KPI network is produced. This was followed by the construction of the weighted supermatrix, which took into consideration the cluster weights so that appropriate normalization of the weights was accorded, without interfering with the relations of the relative importance discovered based on expert appraisals. The limiting supermatrix was obtained by iterative raising to convergence and 15 iterations were needed to be converged to the rounding tolerance of 0.001. This has showed a quick convergence, which has shown that there was a good structural stability within the network and confirmed that the interdependency structure derived using DEMATEL was acceptable.

To give crisp priority values that can be used in decision-making the final global weights were defuzzified by the centroid method out of limited super matrix. Table 3 gives the total ranking result including the weight analysis.

Table 3: Fuzzy ANP Results - Comprehensive KPI Rankings and Weight Analysis

Rank	KPI	Global Weight	Normalized Weight	Cluster Contribution	Priority Tier
1	Emergency Response Time (K1)	0.128	12.8%	0.352	Critical
2	Supply Chain Flexibility Index (K5)	0.115	11.5%	0.414	Critical
3	Real-time Inventory Visibility Rate (K9)	0.102	10.2%	0.389	Critical
4	Digital Integration Score (K10)	0.094	9.4%	0.359	High
5	Critical Supply Stockout Frequency (K2)	0.087	8.7%	0.240	High
6	Vendor Diversification Index (K6)	0.079	7.9%	0.284	High
7	Emergency Inventory Activation Time (K3)	0.074	7.4%	0.204	High
8	Demand Forecast Accuracy (K11)	0.068	6.8%	0.260	Moderate
9	Supplier Response Time (K7)	0.063	6.3%	0.227	Moderate
10	Order-to-Delivery Cycle Time (K12)	0.058	5.8%	0.221	Moderate
11	Crisis Communication Response Time (K4)	0.054	5.4%	0.149	Moderate
12	Last-Mile Delivery Success Rate (K13)	0.049	4.9%	0.505	Low
13	Cold Chain Integrity Rate (K14)	0.045	4.5%	0.464	Low
14	Multi-Modal Transportation Utilization (K8)	0.041	4.1%	0.147	Low

3.3 Causal Loop Analysis and System Dynamics

The integration of the FDEMATEL and FANP gives the complex causal loops that offer ideas on the dynamics of the system and methods of its improvement. The strongest positive feedback loop connects Emergency Response Time (K1) → Real-time Inventory Visibility Rate (K9) → Digital Integration Score (K10) → Supply Chain Flexibility Index (K5) → Emergency Response Time (K1). This loop indicates that investments in any component generate reinforcing improvements throughout the system.

A secondary feedback loop involves Vendor Diversification Index (K6) → Emergency Inventory Activation Time (K3) → Critical Supply Stockout Frequency (K2) → Supply Chain Flexibility Index (K5), suggesting that supply base diversification creates cascading resilience improvements. These causal relationships provide valuable guidance for implementing systematic improvement programs that leverage positive reinforcement mechanisms.

4. Discussion on Findings

This section will provide the elaboration of the research findings, putting it into perspective of current situation within the discourse of healthcare supply chain management and recent empirical studies carried out in post-pandemic time-span. In particular, the discussion gives a very important lesson and insight in synthetic arrangement of the study of Fuzzy DEMATEL-ANP and location of the findings within current trend of healthcare supply network transformation programmatic frameworks.Six KPIs were categorised into cause factors (K1, K3, K5, K6, K9, K10), which are the basic drivers or critical or very strong determinants of other dimensions of performance. Eight KPIs also became effect factors (K2, K4, K7, K8, K11, K12, K13, K14). It implies that they are responsive to driving factor improvements. Emergency Response Time (K1) had the highest value of prominence (R+C = 8.924) and causal influence (R-C = 0.847) to show that it is the main lever in increasing the responsiveness of healthcare supply chains. Supply Chain Flexibility index (K5) became ranked second (R-C = 0.623) in the concept of causes that influenced responsive operations, justifying theoretical insights on agility as a core organizational capability of certain environments (Jaafar, M. et al., 2025).

Creating single KPIs and joining the outcomes to a cluster level helps gain strategic information on how to handle healthcare chain supply. Emergency Response & Time-Critical Operations cluster showed the highest overall effect (cumulative R-C = 1.157) and Digital Integration & Visibility cluster had the second highest overall effect (cumulative R-C = 0.957). The current supply chain priorities model used by the modern healthcare system fits into this hierarchy, where emergency preparedness and technological sustainability are viewed as key building blocks (Apeh, C. E. et al., 2024). The Supply Chain Agility & Flexibility cluster had a modest (but significantly) causal role (cumulative R-C = 0.754) and Quality Assurance & Compliance cluster was an effect one (cumulative R-C = -0.623). This trend implies that enhanced emergency response capacities, digital integration, and flexibility in operations are the key drivers regarding quality outcomes and are not independent performance drivers.

Digital Integration & Visibility represented 26.2% of the total weight and depicts that there is increased significance to technological enablement in healthcare supply chain management. Quality Assurance & Compliance was considered important to regulatory compliance and was given 9.7-percent total weight, which established it as a supporting factor as compared to the factors involved to operate according to responsiveness in aspect. Such weight distribution comes as a good guide to strategic resource assignments and prioritization on improving measures to be adopted in healthcare supply chain management efforts.

5. Theoretical Implications & Practical Implications

5.1 Theoretical Implications

The results of analysis that determine Emergency Response Time to be the most important KPI confirm the unusual nature of healthcare supply chains where time is the performance metric that is directly related to patient outcomes. The result enriches the classic theory of supply chain responsiveness by defining new performance hierarchies in the field of healthcare that cannot directly apply to the typical manufacturing environment. The current research has resulted in the empirical support of dynamic capability theory in medical environment; Supply Chain Flexibility Index being the strong causal driver highlighted the significance of adaptive organizational ability in the successful adaptation to disruption via expedient reconfiguration of organizational resources. The COVID-19 pandemic proved the best confirmation of this hypothesis and the distinctiveness and flexibility of healthcare organizations in adapting to previously unknown rises in demand. Therefore the existence of digital integration KPIs gives good empirical evidence of the application of information processing theory to healthcare supply chains. The new study has shown that digital technologies also serve as sources of information processing capability, which increases supply chain coordination and decision-making in the face of uncertainty (Rashid, A. et al., 2024).

5.2 Practical Implications

The practical implications of the research findings pose important results of useful application of the information in the healthcare supply chain management providing evidence-based recommendations in the areas of strategic decision-making and resource appropriation. Emergency Response Time has been ranked as the most important parameter; therefore, there should be a strong motive to pump in capital in building up infrastructure to support emergency preparedness. Recent analysis in the industry shows that 96 percent of manufacturing CEOs are considering supply chain operations to build resilience and similarly, healthcare organizations identify their priority in the capability of responding to emergencies**.** The second priority tier also marks the strategic level of development of organizational flexibility features, namely to quickly respond to changes. To avoid dependency risks, it is advised that healthcare organizations must come up with supplier diversification strategies such as geographic and capability-based diversity. Digital integration KPIs on a high ranking highlight strategic need of whole-scale Digital transformation programs. Latest statistics show that 45 percent of hospitals have migrated to cloud-based supply chain management and the cost saving due to digital transformation could save up to 50 percent and generate an increase of 20 percent in revenues.

6. Conclusion

This study is the first effort of developing advanced framework in terms of modeling and prioritization of KPIs in responsive healthcare supply chain management in emerging economies and more specifically in India. The study captures the complexities of interdependences found in a healthcare supply chain through the study. The paper involves the use of innovative combination of Fuzzy DEMATEL and Fuzzy ANP approaches to account interdependencies and uncertainties that define the performance measurement of a healthcare supply chain. According to the investigation, it is possible to decide that Emergency Response Time will be considered to be the most significant performance indicator (weight 12.8 percent) and Supply Chain Flexibility Index and Real-time Inventory Visibility Rate (11.5 and 10.2 per cent, respectively). These results confirm that in terms of healthcare operations and supply chain, the life-critical nature of the operations justifies the direct connection between time-based performance and patient results, and the healthcare supply chain does not occur in a traditional context. The study can help care managers develop a powerful three level prioritization system to offer them structured direction in their area of concern: resource allocation and performance improvement plans. The DEMATEL analysis shows vital cause-and-effect relationships and determines six cause KPIs that influence system performance and eight effect KPIs that react to changes to causal factors improvement. Theoretically, the study expands the theory of supply chain responsiveness, developing the performance hierarchies that are specific to the healthcare sector due to its peculiarities in operation. The study offers an empirical confirmation of the dynamic capability theory and information processing theory utilization within a healthcare scene as it proves the importance of flexibility in organizations and digital technologies to act as the driving force behind responsive performance. The results have considerable strategic implications to the healthcare practice, as it offers evidence-based advice on where to make investment decisions related to emergency response capabilities, supply chain flexibility development, and digital transformation efforts. The study facilitates formatting policies on national emergency supply chain networks, digitalization agenda in healthcare, and supply chain localization processes. Although the study is specifically addressing the Indian situation regarding healthcare, the results are quite universal and showcase a high degree of applicability to healthcare systems in general, more specifically the emerging economies, which might face similar infrastructure issues. The methodology proposes a generalizable method of modeling the performance of healthcare supply chain applicable across various healthcare systems facilitated by the suitable adaptation of the meaning of the KPIs and their assessment by experts.

7. Limitations and Future Research Directions

There are some limitations that should be noted on the interpretation and the application of the research. The research is explicitly performed on the Indian context of healthcare and practical conclusions could need modification to fit other nations with distinct and various healthcare system formats and regulatory situations. The expert sample, as well chosen as it is, reflects the assessment at a given time and therefore might miss the changing viewpoints as healthcare systems due to new technologies and operating challenges adjust themselves. The study uses a static analysis that records the relationships between key performance intervention at a particular instant when this is not factored into the dynamic nature of these relationships under various operational contexts. The framework is more geared towards responsiveness and the other dimensions of performance may not be fully encompassed in it like the sustainability of performance, cost optimization, or a long-term strategic development are not fully expressed in said framework.

Future studies need to identify dynamic modeling methodologies that would reflect the changing relationship between KPIs as the operation would be exposed to various scenarios, such as emergency response and technological breakdown. Comparative studies across several countries would help in distinguishing the existence of universal factors against the contextual factors, which would increase generalizability of results. There is need to expand research to reflect sustainability aspects, network-level performance optimization and implementation practical issues such as change management requirement.

The use of machine learning, artificial intelligence and big data analytics to the modeling of healthcare supply chain performance is an exciting research avenue. Future research may include the analysis of the role of predictive analytics in improving the precision of KPIs forecasting and artificial intelligence contribution to dynamic performance optimization.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest: The authors declare no conflicts of interest.

Data Availability Statement: The data supporting this study's findings are available from the corresponding author upon reasonable request, subject to ethical approval and participant consent.

References

1. Apeh, C. E., Odionu, C. S., Bristol-Alagbariya, B., Okon, R., & Austin-Gabriel, B. (2024). Reviewing healthcare supply chain management: Strategies for enhancing efficiency and resilience. Int J Res Sci Innov, 5(1), 1209-16.
2. Araujo, R., Fernandes, J. M., Reis, L. P., & Beaulieu, M. (2023). Purchasing challenges in times of COVID-19: resilience practices to mitigate disruptions in the health-care supply chain. Journal of Global Operations and Strategic Sourcing, 16(2), 368-396.
3. Bathaei, A. (2024). Agile Supply Chains: A Comprehensive Review of Strategies and Practices for Sustainable Business Operations. Journal of Social, management and tourism letter, 2024, 1-13.
4. Badwan, N. (2025). Role of supply chain partnership, cross-functional integration, responsiveness and resilience on competitive advantages: empirical evidence from Palestine. The TQM Journal, 37(5), 1385-1417.
5. Burlea-Schiopoiu, A., & Ferhati, K. (2020). The managerial implications of the key performance indicators in healthcare sector: A cluster analysis. In Healthcare (Vol. 9, No. 1, p. 19). MDPI.
6. Chigboh, V. M., Zouo, S. J. C., & Olamijuwon, J. (2024). Predictive analytics in emergency healthcare systems: A conceptual framework for reducing response times and improving patient care. World, 7(02), 119-127.
7. Chen, Z. S., & Ruan, J. Q. (2024). Metaverse healthcare supply chain: Conceptual framework and barrier identification. Engineering Applications of Artificial Intelligence, 133, 108113.
8. Chen, Y. S., Chuang, H. M., Sangaiah, A. K., Lin, C. K., & Huang, W. B. (2019). A study for project risk management using an advanced MCDM-based DEMATEL-ANP approach. Journal of Ambient Intelligence and Humanized Computing, 10, 2669-2681.
9. Christopher, M., & Holweg, M. (2017). Supply chain 2.0 revisited: a framework for managing volatility-induced risk in the supply chain. International Journal of Physical Distribution & Logistics Management, 47(1), 2-17.
10. Dahinine, B., Laghouag, A., Bensahel, W., Alsolamy, M., & Guendouz, T. (2024). Evaluating performance measurement metrics for lean and agile supply chain strategies in large enterprises. Sustainability, 16(6), 2586.
11. Fallahnezhad, M., Langarizadeh, M., & Vahabzadeh, A. (2024). Key performance indicators of hospital supply chain: a systematic review. BMC Health Services Research, 24(1), 1610.
12. Frederico, G. F., Garza-Reyes, J. A., Anosike, A., & Kumar, V. (2019). Supply Chain 4.0: concepts, maturity and research agenda. Supply Chain Management: An International Journal, 25(2), 262-282.
13. Göncü, K. K., & Çetin, O. (2022). A decision model for supplier selection criteria in healthcare enterprises with dematel ANP method. Sustainability, 14(21), 13912.
14. Jaafar, M., Khan, K. N., & Salman, A. (2025). A systematic review and framework for organizational agility antecedents towards industry 4.0. Management Review Quarterly, 1-26.
15. Jia, F., Aboagye, S., Shahzadi, G., & Chen, L. (2025). Sustainable practices in healthcare supply chains: a review of strategies, challenges, and impacts. International Journal of Logistics Research and Applications, 1-25.
16. Karatas, M., Eriskin, L., Deveci, M., Pamucar, D., & Garg, H. (2022). Big Data for Healthcare Industry 4.0: Applications, challenges and future perspectives. Expert Systems with Applications, 200, 116912.
17. Kalaria, C., Singh, S., & Prajapati, B. G. (2023). Intelligent Healthcare Supply Chain. Human-Machine Interface: Making Healthcare Digital, 449-481.
18. Li, X., Zhao, X., Lee, H. L., & Voss, C. (2023), "Building responsive and resilient supply chains: Lessons from the COVID-19 disruption". Journal of Operations Management, 69(3), 352-358.

19. McGuinn, J. N. (2021). Lessons learned from COVID-19: Best practices for building a more resilient healthcare supply chain. Management in Healthcare, 5(3), 274-288.
20. Mishra, N. K., Pande Sharma, P., & Chaudhary, S. K. (2025). Redefining agile supply chain practices in the disruptive era: A case study identifying vital dimensions and factors. Journal of global operations and strategic sourcing, 18(1), 64-90.
21. Munir, M., Jajja, M. S. S., & Chatha, K. A. (2022). Capabilities for enhancing supply chain resilience and responsiveness in the COVID-19 pandemic: exploring the role of improvisation, anticipation, and data analytics capabilities. International Journal of Operations & Production Management, 42(10), 1576-1604.
22. Nabovati, E., Farrahi, R., Sadeqi Jabali, M., Khajouei, R., & Abbasi, R. (2023). Identifying and prioritizing the key performance indicators for hospital management dashboard at a national level: viewpoint of hospital managers. Health Informatics Journal, 29(4).
23. Pamucar, D., Torkayesh, A. E., & Biswas, S. (2023). Supplier selection in healthcare supply chain management during the COVID-19 pandemic: a novel fuzzy rough decision-making approach. Annals of Operations Research, 328(1), 977-1019.
24. Pedro Senna, Augusto Reis, Ana Dias, Ormeu Coelho, Julio Guimarães & Severo Eliana (2021), "Healthcare supply chain resilience framework: antecedents, mediators, consequents", Production Planning & Control, DOI: 10.1080/09537287.2021.1913525.
25. Rashid, A., Rasheed, R., Ngah, A. H., Pradeepa Jayaratne, M. D. R., Rahi, S., & Tunio, M. N. (2024). Role of information processing and digital supply chain in supply chain resilience through supply chain risk management. Journal of Global Operations and Strategic Sourcing, 17(2), 429-447.
26. Rehman, N., Anjum, R., & Petros, F. B. (2025). Consensus based sustainable decision making using probability hesitant fuzzy preference relations with application on risk assessment in food industry. Scientific Reports, 15(1), 4135.
27. Saha, E., & Rathore, P. (2024). The impact of healthcare 4.0 technologies on healthcare supply chain performance: Extending the organizational information processing theory. Technological Forecasting and Social Change, 201, 123256.
28. Sarangi, S., & Ghosh, D. (2024). The impact of industry 4.0 technologies enable supply chain performance and quality management practice in the healthcare sector. The TQM Journal.
29. Spieske, A., Gebhardt, M., Kopyto, M., & Birkel, H. (2022). Improving resilience of the healthcare supply chain in a pandemic: Evidence from Europe during the COVID-19 crisis. Journal of Purchasing and Supply Management, 28(5), 100748.
30. Scala, B., & Lindsay, C. F. (2021). Supply chain resilience during pandemic disruption: evidence from healthcare. Supply Chain Management: An International Journal, 26(6), 672-688.
31. Sharma, A., Gupta, P., & Jha, R. (2020). COVID-19: Impact on health supply chain and lessons to be learnt. *Journal of Health Management*, *22*(2), 248-261.
32. Tortorella, G. L., Prashar, A., Antony, J., Fogliatto, F. S., Gonzalez, V., & Godinho Filho, M. (2024). Industry 4.0 adoption for healthcare supply chain performance during COVID-19 pandemic in Brazil and India: the mediating role of resilience abilities development. Operations Management Research, 17(2), 389-405.