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Identifying and addressing disruptions in healthcare supply chain management

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Abstract

The COVID-19 pandemic has put a spotlight on the global supply chain for medical equipment and medicines, highlighting vulnerabilities and disruptions in the healthcare industry. This paper aims to contribute to the ongoing research on enhancing supply chain resilience in healthcare by exploring the critical issues surrounding supply chain management in this sector and presenting strategies aimed at identifying and mitigating disruptions. Specifically, we propose a model using fuzzy logic to address the inherent uncertainty in analyzing key barriers in supply chain management for the healthcare industry. Our findings emphasize the crucial need for robust and adaptable supply chains to ensure a consistent supply of essential medical resources, especially during times of crisis.

Keywords: Supply Chain Management; Healthcare Industry; Decision-Making Model; Resilience Strategies

1. Introduction

Healthcare supply chains have unique complexities and responsibilities, handling valuable medical resources and safeguarding human lives (Chatterjee et al., 2023). However, healthcare systems worldwide face growing pressures as they need to reduce costs, enhance efficiency, improve quality, and ensure consistent care. During crises, healthcare supply chains often face sudden demand spikes, leading to shortages of critical supplies. They must balance maintaining inventory buffers to ensure availability without causing wastage. Reliance on single suppliers for essential items increases vulnerability, as disruptions from one vendor can have far-reaching consequences. The complexity of global sourcing, with components originating from various locations, means that disruptions can resonate throughout the entire chain. Also, strict regulations need compliance across all suppliers, avoiding to risk recalls, delays, and potential legal action.

Managing unpredictable demand, diversifying supplier sources, navigating international logistics, and ensuring regulatory compliance within decentralized networks are significant challenges (Junaid et al., 2023). The primary goal is to assess and mitigate disruptions to maintain service levels, prevent shortages, and streamline operations. The surge in online shopping during the pandemic highlights the importance of optimizing transport processes (Feichtinger et al., 2020). As more consumers turn to digital platforms for medical purchases, healthcare providers need tailored decision-making models for efficient transport, inventory management, and procurement strategies. This trend emphasizes ongoing challenges such as dependency on single suppliers and the need to comply with complex global regulations in healthcare supply chains.

This research aims to introduce a decision-making model for identifying key barriers in the healthcare sector while providing tailored recommendations for addressing these challenges.

The paper is organized as follows. Section 2 develops the literature review, section 3 describes methodological details, while section 4 reports a real case study along with a practical discussion of results. Section 5 closes the work by discussing potential future lines.

2. State of the art

The study led by Kaupa and Naude (2021a) discusses the importance of addressing significant factors that can increase expenses in supply chain management. To maintain performance targets and financial stability, it is crucial for supply chain partners to proactively identify and eliminate obstacles via effective decision-making (El Mokrini and Aouam, 2022; Rivas Pellicer et al., 2023). Key cost-related issues include poor demand forecasting leading to planning disruptions, financial constraints resulting in stock shortages, an excessive reliance on highways for distribution, limited storage capacity, and insufficient coordination among various entities (Arji et al., 2023). These challenges can harm the efficiency of the supply chain.

To enhance performance and minimize costs, it is essential to focus on obstacle management, adequate staffing, and improved coordination (Menezes and Carpitella, 2023) throughout the healthcare commodities supply chain. By paying close attention to areas like demand forecasting, procurement, inventory management (Tungekar et al., 2023), logistics, and integration, supply chain performance can be effectively assessed (Azadi et al., 2023) so as to identify areas for cost reduction. Kanyoma et al. (2013) aimed to highlight significant supply chain implications within the healthcare context. The presence of insufficient drug supplies had severe repercussions, leading to patient fatalities within the public healthcare system. A primary cause of this issue refers to the structure of the network. For example, as observed by Habibi et al. (2023), supply chain networks characterized by multiple tiers of suppliers are more susceptible to disruptions. This vulnerability arises because a disruption occurring at one tier can propagate through the network, resulting in a cascading effect, commonly referred to as the ripple effect (Sawik, 2022). To mitigate such risks, multiple sourcing strategies, including backup sources, could be adopted as preventive strategies. In this context, it is important to recognize that supply chain performance is defined by its resilience, sustainability, and cyber-security. While these three aspects can be assessed individually to determine a supply chain's strength, it is the collective evaluation of all three that provides a holistic understanding of the system's ability to operate smoothly without disruptions and quickly recover if challenges arise (Hossain et al., 2023). Okeagu et al. (2021) emphasize how crises impact supply chain management. Unforeseen shortages can arise when there is an imbalance between supply and demand or when disruptions occur. Effectively managing emergencies requires accurate planning, and it is essential to have separate systems for emergencies.

This separation is important as crises often require specialized infrastructure and processes that are different from the routine supply chain operations. This also ensure flexibility and transparency of the organisational management system, based on robust and diversified supply chain (Kumar et al., 2023). Response relies on infrastructure (transportation, communication, energy) and leadership at local and state levels for coordination. A comprehensive planning across infrastructure, protocols, communications, and governance to ensure resilient crisis management (Barbosa-Póvoa and Pinto, 2023), is indeed essential for preserving the integrity of supply chains during interruptions. Kaupa and Naude (2021b) aimed to highlight important supply chain management issues with a practical focus on the public healthcare system in Malawi. Despite the government's responsibility to ensure an efficient healthcare supply chain, Malawi continues to face recurring shortages of essential medications. With this regard, the authors emphasized that certain Critical Success Factors (CSFs) could either support or hinder excellence in the supply chain. When these CSFs are not managed properly, it can increase the vulnerability and risk within the system.

As the main objective of supply chain management is to deliver value to end-users, which benefits both businesses and the general public, strategies that enhance efficiency and competitiveness are necessary. Abdulsalam and Schneller (2019) aimed to analyze the inherent complexities of hospital supply chains for various reasons. First, healthcare systems have extensive relationships with a wide array of stakeholders, including manufacturers, distributors, Group Buying Organizations (GPOs), and insurers, which adds complexity to the management process. Second, hospital executives need to assess both internal procedures and the external structures and partnerships that impact supply costs. In light of these considerations, the authors investigated whether affiliating with large or small GPOs, or having multiple GPOs, improves supply cost performance and what the ideal balance between GPO, distributor, and direct supplier contracts should be. While some empirical research has examined the best practices in healthcare supply management to understand cost-saving effectiveness, more precise data on supplier costs is needed (Levner and Herbon, 2023).

In light of the various challenges outlined in these studies, developing a decision-making model in the healthcare sector (Chakraborty et al., 2023) can be an useful tool to assess major barriers and provide effective recommendations. This model would facilitate a comprehensive evaluation of critical barriers, supporting in addressing complexities and vulnerabilities, and offering a structured path to optimize healthcare supply chains. With this regard, Fuzzy Cognitive Maps (FCM) can be highly valuable (Bamakan et al., 2021), as barriers related to healthcare supply chains involve a multitude of interconnected variables and relationships, something that can be challenging to model using traditional methods.

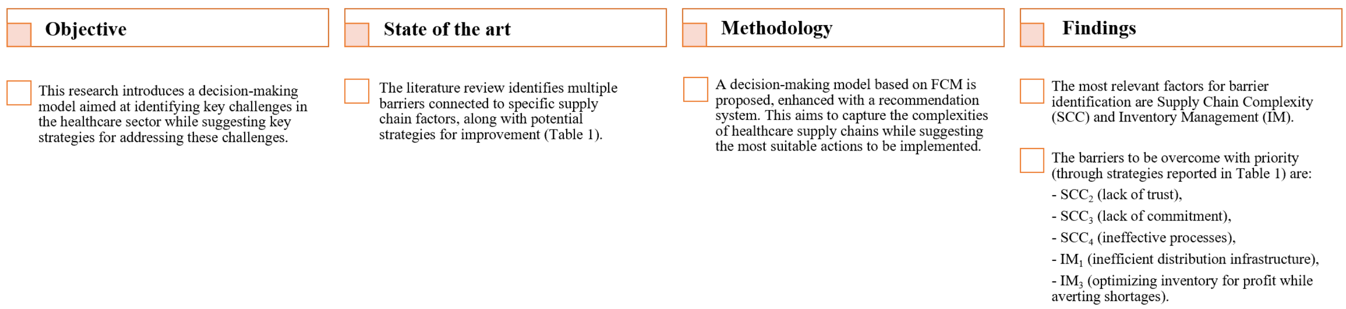

Figure 1. Diagram for decision-making model in healthcare supply chain

After identifying multiple barriers in the literature and summarizing them in Table 1, our next step involves the development of a FCM-based decision-making model, enhanced with a recommendation system. This upgraded FCM not only captures the complexities of the supply chain but also has the capability to promptly suggest the most suitable actions to be implemented, prioritizing them based on the specific context and needs.

Figure 1 presents a diagram exemplifying the logical sequence followed in this research, illustrating our novel approach. Grounded upon existing literature, our approach stands out by systematically quantifying qualitative assessments of factors and barriers, thus enabling their integration into a mathematical model based on FCM. This procedure is aimed at bridging the gap between qualitative insights and quantitative analysis, providing a structured framework for addressing complex challenges in healthcare supply chains through targeted strategies.

3. Methodology

FCMs are a modeling and simulation technique used in various fields such as artificial intelligence, decision support systems, and expert systems. This tool is particularly useful for representing and simulating complex systems with interconnected variables. A step-by-step description of the FCM approach is herein provided.

- System definition: begin by precisely articulating the boundaries of the decision-making problem, identifying key elements or variables that contribute to the complexity of the system under consideration. This step involves a comprehensive understanding of the system's objectives and constraints.
- Linguistic evaluation: conduct a thorough exploration of qualitative assessments and expert opinions, expressing the relationships between identified elements in linguistic terms. This involves eliciting input from domain experts to capture nuanced insights and subjective judgments.
- Translate to fuzzy numbers: translate the linguistic evaluations into fuzzy numbers, using well-defined membership functions to capture the vagueness and imprecision inherent in qualitative assessments.
- Fuzzy-to-Crisp translation: translate fuzzy numbers to crisp numerical values for computational purposes. Such established methods as centroid defuzzification can be used to obtain representative crisp values. This approach quantifies qualitative assessments, making them suitable for mathematical modeling.
- Graphical representation: construct a FCM graph with nodes representing decision elements and directed edges indicating relationships between them. Assign weights to edges based on the translated crisp numerical values, reflecting the strength and direction of influence. This step involves the graphical depiction of the complex interconnections within the system.
- Simulation and calculation: first define the initial conditions for each decision element in the FCM. These initial values serve as the starting point for simulations, providing a baseline for the iterative modeling process. Then execute simulations of the FCM over time, updating the values of decision elements based on their relationships and initial conditions. Calculate indirect effects by systematically summing the products of weights along pathways. Concurrently, compute total effects by summing the direct and indirect effects for each decision element.
- Validation and adjustment: rigorously validate the FCM results by comparing simulated outcomes with empirical data or expert expectations. Adjust linguistic evaluations, fuzzy numbers, or other model parameters iteratively to enhance the alignment of the model with observed real-world behavior.
- Iterative refinement: engage in an iterative refinement process by incorporating additional data, fine-tuning linguistic evaluations, and adjusting model parameters. This iterative approach ensures that the FCM evolves to accurately represent the complexities of the decision-making system.
- Decision insights: analyze the calculated total effects to derive nuanced insights into the significance of each decision element's impact on the overall system. This quantitative understanding facilitates informed decision-making by elucidating critical factors and their interdependencies.

Table 1. Factors, related barriers and recommended strategies analyzed in literature

ID	Factors	Barriers	Recommended Strategies	Ref.
SCC	Supply Chain Complexity	SCC_1. Lack of collaboration and communication	• Improve communication and partnerships between stakeholders. • Establish cross functional teams and share key metrics and plans across the supply chain. • Promote collaborative culture between partners and align incentives to shared goals. • Establish open communication channels between partners and schedule regular meetings. • Engage partners in collaborative forecasting, planning and problem solving. • Implement shared platforms for seamless data exchange, and digitize records.	Hudnurkar et al. (2014), Kaupa and Naude (2021a)
		SCC_2. Lack of trust	• Foster trust via long term partnerships and share critical data to demonstrate trustworthiness. • Structure contracts and relationships to incentivize shared goals. • Identify assets, skills and data that can be mutually shared and develop resource sharing agreements. • Develop relationships at personal level and maintain transparency and integrity.	Kaupa and Naude (2021b), Hudnurkar et al. (2014)
		SCC_3. Lack of commitment	• Executive leadership must own and sponsor supply chain initiatives. • Set standards for social and environmental practices while enforcing supplier codes of conduct. • Implement contractual agreements clearly outlining commitments and build relationships and trust through transparency.	Hudnurkar et al. (2014)
		SCC_4. Ineffective processes	• Streamline tendering and procurement protocols and automate ordering and approval workflows. • Map and optimize workflows for efficiency standardize processes across locations. • Simulate crisis scenarios and preparedness plans while negotiating contingency capacity with key suppliers in advance. • Conduct supplier market analysis and develop strategies to mitigate risk. • Map end to end processes to identify integration gaps and standardize interfaces between parties. • Invest in technologies like AI, IoT, blockchain to boost performance. • Define clear roles and responsibilities while tracking individual performance and accountability. • Develop and implement optimization models to streamline network design. • Define quantitative metrics for supplier selection and performance management.	Kanyoma et al. (2013), Kaupa and Naude (2021b), Hudnurkar et al. (2014)
		SCC_5. Exogenous barriers	• Assess current and projected needs before accepting donations while enforcing guidelines on types and volumes of donations. • Establish supply chain compliance guidelines and audit governance mechanisms periodically. • Develop flexible systems and processes that can rapidly adapt to changes. • Develop contracts that align with regulations and protect IP rights. Consult legal experts. Okeagu et al. (2021) • Lobby government agencies to promote policies that support collaboration.	Kanyoma et al. (2013), Kaupa and Naude (2021a), Kaupa and Naude (2021b),
RC	Regulatory Compliance	RC_1. Outdated standard guidelines	• Regularly update treatment guidelines based on new research.	Kaupa and Naude (2021a)
		RC_2. Narrow range of reg. products	• Streamline product registration process.	Kaupa and Naude (2021a)
QC	Quality Control	QC_1. Poor data consumption quality	• Implement systems to collect accurate consumption and patient data.	Kaupa and Naude (2021a)
		QC_2. Lack of skilled human resources	• Invest in training and education programs for healthcare workers.	Kaupa and Naude (2021a)
GF	Geopolitical Factors	GF_1. Weak governance and accountability mechanisms	• Strengthen organizational governance and transparency.	Hudnurkar et al. (2014)

ID	Factors	Barriers	Recommended Strategies	Ref.
		GF_2. Cultural differences	• Provide cultural awareness training and foster an inclusive environment.	Hudnurkar et al. (2014)
SR	Supplier Reliability	SR_1. Inadequate capacity	• Support local manufacturing and supply capacity building.	Kaupa and Naude (2021a)
		SR_2. Over-reliance on single suppliers	• Qualify and maintain backup suppliers for critical items and limit sourcing concentration from a single region. • Develop a diversified supplier base by geography and size and require secondary sources for all key materials	Okeagu et al. (2021)
		SR_3. Sourcing from multiple locations	• Source each item from at least two different supplier locations and mandate regional redundancy for suppliers.	Okeagu et al. (2021)
		SR_4. Poor supplier relationships	• Implement supplier relationship management and collaborate on forecasting and planning.	Kaupa and Naude (2021b)
		SR_5. Inadequate storage	• Improve storage and warehouse infrastructure capacity.	Abdulsalam and Schneller (2019), Kaupa and Naude (2021a)
TC	Transportation Costs	TC_1. Inefficient distribution infrastructure	• Develop efficient distribution networks and logistics capabilities.	Kaupa and Naude (2021a)
		TC_2. Transportation infrastructure	• Expand central and regional warehouse capacity while adding refrigerated transportation vehicles.	Kanyoma et al. (2013)
IM	Inventory Management	IM_1. Lack of inventory management system	• Implement digital inventory management systems.	Kaupa and Naude (2021a)
		IM_2. Donations of medicines nearing their expiration date	• Institute First Expiry First Out (FEFO) rotation return soon to expire drugs to donors.	Kanyoma et al. (2013)
		IM_3. Optimizing inventory for profit while averting shortages	• Use demand forecasting and inventory optimization models, and increase safety stock.	Okeagu et al. (2021), Abdulsalam and Schneller (2019)
		IM_4. Theft or loss of supplies	• Track inventory with barcode or Radio Frequency Identification (RFID) systems and improve physical security at warehouses.	Kanyoma et al. (2013)
LC	Labor Costs	LC_1. Lack of human resources	• Invest in healthcare workforce training and development.	Kaupa and Naude (2021a), Abdulsalam and Schneller (2019)
		LC_2. Unclear role definition	• Invest in training programs to upskill supply chain staff. • Automate repetitive tasks to optimize human resource utilization.	Abdulsalam and Schneller (2019)
		LC_3. Inefficient management of human resources	• Implement robust management systems to efficiently allocate staff and balance workloads. • Cross-train employees to provide flexibility in resource allocation.	Abdulsalam and Schneller (2019)
DF	Demand Fluctuations	DF_1. Lack of financial resources	• Increase healthcare funding and financing options.	Kaupa and Naude (2021a)
		DF_2. Panic driven overordering	• Collaborate with customers to stabilize orders. • Enforce order quantity limits during periods of high demand.	Okeagu et al. (2021)
TA	Technological Advancements	TA_1. Lack of knowledge of the pharmaceutical market	• Conduct pharmaceutical market research and data analysis.	Kaupa and Naude (2021a)
		TA_2. Ineffective utilization of information technologies	• Deploy integrated supply chain management systems and mandate technology usage and data capture.	Kaupa and Naude (2021b)
		TA_3. Unreliable logistical information systems	• Implement inventory management software integrated with suppliers' systems for stock visibility.	Kanyoma et al. (2013)
EF	Economic Factors	EF_1. High cost of medicines and treatment	• Negotiate reduced medicine costs, utilize generics.	Kaupa and Naude (2021a)
		EF_2. Boosting domestic manufacturing	• Provide incentives to manufacture critical supplies locally and invest in developing domestic production capabilities.	Okeagu et al. (2021)
		EF_3. Supply chain costs	• Use data analytics to identify cost savings opportunities. • Renegotiate supplier and logistics contracts. • Increase health budget allocation. • Explore public private partnerships.	Abdulsalam and Schneller (2019)
		EF_4. Lack of robust procurement systems	• Centralize and automate procurement processes.	Kaupa and Naude (2021a)
		EF_5. Poor specification and quantification	• Improve demand planning and forecasting capabilities.	Hudnurkar et al. (2014),Kaupa and Naude (2021a)

Specifically, indirect effects (IE) represent the influence that a particular decision element has on another element through intermediate elements. It captures the cascading impact as changes in one element affect others, creating a chain reaction. Total effects (TE) incorporate both the direct and indirect impacts of a decision element on the entire system. It reflects the overall contribution of a particular element, considering not only its direct influence on other elements but also the indirect effects propagated through the network. IE and TE have to be computed for each of the decision-making element taken into account. In this paper, we will follow the procedure implemented in (Carpitella et al., 2023). The linguistic evaluations of input characterize the degree of causality one element imparts to another, denoted by labels such as very low (VL), low (L), medium (M), high (H), and very high (VH). These labels are correspondingly translated into Trapezoidal Fuzzy Numbers (TrFNs), following the format (a, b, c, d), as per (Poomagal et al., 2021): VL (0, 0.1, 0.2, 0.3); L (0.2, 0.3, 0.4, 0.5); M (0.4, 0.5, 0.6, 0.7); H (0.6, 0.7, 0.8, 0.9), and VH (0.8, 0.9, 1, 1). These TFNs are systematically organized in the fuzzy input matrix. Following that, the defuzzification process occurs through the implementation of a defuzzification function. This function undergoes iteration by calculating the centroid of gravity for each TrFN, a methodology detailed by Wang et al. (2006). The result of this operation yields crisp values, effectively substituting the initial TrFNs. Consequently, these crisp values are consolidated in the crisp input matrix, representing the defuzzified versions of the TrFNs. Each entry in the matrix now includes a singular crisp value rather than a TrFN.

Subsequently, we proceed to compute both indirect and direct effects for each element derived from the crisp matrix. To facilitate result visualization, we employ a layered organization of the FCM graph. Each layer consists of elements with the same value of TE, arranged in a descending order. This structured representation enables a clear prioritization, emphasizing that elements in the first layer demand particular attention due to their higher impact within the system. The visualization technique adopted in this approach offers a visually rich representation of the varying strengths of connections among elements within the FCM, by using arrows of distinct thicknesses and colors to effectively convey the strength of relationships established by the experts in linguistic terms.

4. Case study

The present case study proposes the iteration of the FCM procedure through two different stages. Initially, we will assess factors outlined in the second column of Table 1, selecting that subset characterized by the highest TE values. In the subsequent stage, we will analyze the barriers associated with the primary factors identified in the prior phase. The objective is to recommend the prioritized implementation of targeted strategies aimed at mitigating these identified barriers. This sequential methodology is strategically designed to amplify the precision and efficacy of our recommendations. Its applicability is notably advantageous in the pharmaceutical sector's supply chain management, systematically pinpointing and prioritizing factors with the most substantial impact on the entire system. By concentrating on these key factors and proactively addressing associated barriers, the approach ensures a more refined and effective implementation of strategies, thereby augmenting overall operational efficiency and fortifying the resilience of the supply chain within the pharmaceutical industry.

4.1. Analysis of factors for main barriers identification

Various brainstorming sessions have been led, aimed at elaborating the linguistic input matrix pairwise comparing factors, reported in Table 2. The reported evaluations have been double-checked with the support of an expert in the field of supply chain management. After translating linguistic evaluations to fuzzy numbers as explained before, we proceeded by calculating the TE associated to each of the analyzed factors. Calculations have been implemented in Python to eventually visualize results.

The resulting FCM is reported in Figure 2. We created a network visualization of relationships between different factors based on their TE values. We constructed a directed graph where nodes represent different factors and edges represent relationships between them, according to the evaluations provided in Table 2. The graph is organized through different layers, with factors grouped according to their associated TE values. Nodes within each layer are positioned horizontally, and layers are arranged vertically. The network diagram provides a clear representation of the hierarchical relationships between factors, emphasizing the most significant factors at the top of the diagram.

Table 2. Linguistic input matrix for factors

	SCC	RC	QC	GF	SR	TC	IM	DF	LC	TA	EF
SCC	0	VL	M	M	L	H	VH	H	H	L	M
RC	H	0	VH	H	M	H	H	M	H	L	H
QC	H	H	0	L	H	L	H	M	M	M	H
GF	H	H	H	0	H	VH	VH	H	H	M	VH
SR	H	L	M	M	0	M	H	H	L	VL	M
TC	H	VL	L	L	M	0	H	H	M	L	H
IM	VH	L	M	L	L	H	0	H	H	L	H
DF	H	H	M	M	L	VH	H	0	H	M	H
LC	H	L	L	L	L	H	H	M	0	H	H
TA	VH	M	H	L	L	M	H	M	VH	0	H
EF	H	M	M	H	M	VH	H	H	H	M	0

By observing the graph displayed in Figure 2, we can conclude that, according to the proposed evaluations, the most prominent factors in healthcare supply chain management from those analyzed in literature (Table 1) are Supply Chain Complexity (SCC) and Inventory Management (IM). These results are important as healthcare sector faces unique challenges due to the unpredictable nature

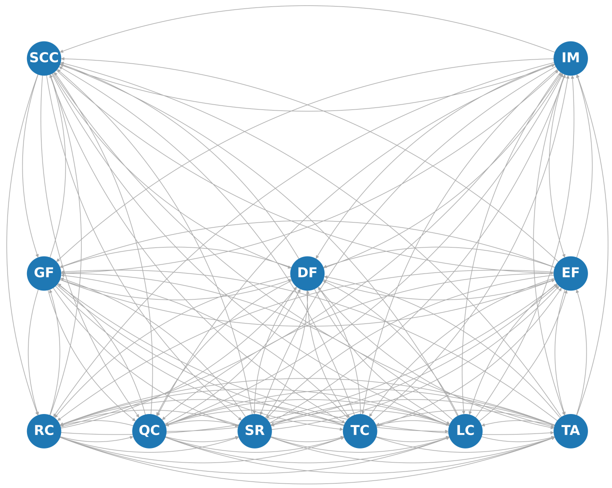

Figure 2. Factors FCM

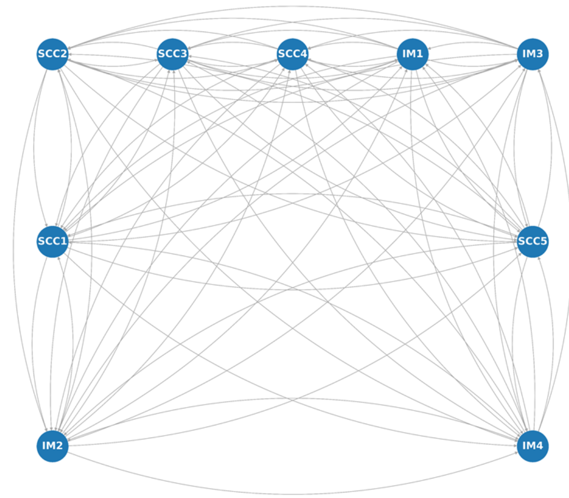

Figure 3. Barriers FCM

of demand, especially during crises. This requires a supply chain that can quickly adapt to changing needs while ensuring timely deliveries of essential medical resources. Additionally, the diverse range of healthcare products, each with specific storage requirements, demands careful inventory management to prevent shortages or wastage. Efficient inventory practices are essential, given the time-sensitive nature of healthcare services. The global scope of healthcare sourcing and compliance with strict regulations further accentuate the need for streamlined processes. In optimizing the healthcare supply chain, the goal is to enhance operational efficiency, ensuring a steady and reliable supply of critical medical resources to meet the demands of patient care. We are now going to analyze the related barriers to propose strategies prioritization.

4.2. Analysis of barriers for strategies recommendation

Table 3 reports linguistic evaluations collected and validated for the barriers of the most prominent factors. As the second iteration for the FCM application,

Table 3. Linguistic input matrix for barriers

	SCC_1	SCC_2	SCC_3	SCC_4	SCC_5	IM_1	IM_2	IM_3	IM_4
SCC_1	0	H	H	M	L	VH	L	M	H
SCC_2	M	0	VH	H	M	H	M	M	M
SCC_3	L	H	0	H	M	M	M	H	L
SCC_4	M	M	H	0	H	H	M	VH	M
SCC_5	M	L	M	L	0	M	H	H	H
IM_1	H	M	H	VH	L	0	M	VH	H
IM_2	L	H	M	H	H	M	0	H	VL
IM_3	M	M	H	L	H	H	H	0	L
IM_4	H	VH	M	H	H	H	VL	H	0

Figure 3 shows the visualization of the network of relationships identified for the barriers related to the factors SCC and IM (Table 1).

The resulting diagram displays barriers with greater TE values positioned at the top, allowing for the immediate identification of the strategies that are recommended with priority. Specifically, the strategies from Table 1 to be prioritized for healthcare supply chain optimization refer to overcoming the following barriers.

- Barrier SCC_2 (lack of trust) - Recommended strategies: 1. foster trust via long term partnerships and share critical data to demonstrate trustworthiness; 2) structure contracts and relationships to incentivize shared goals; 3) identify assets, skills and data that can be mutually shared and develop resource sharing agreements; 4) develop relationships at personal level and maintain transparency and integrity. Implementing these strategies would result in improved collaboration and reduced instances of miscommunication. Long-term partnerships and data sharing can indeed enhance the reliability of supply chain operations, fostering a more cooperative environment among stakeholders.
- SSC_3 (lack of commitment) - Recommended strategies: 1) executive leadership must own and sponsor supply chain initiatives; 2) set standards for social and environmental practices while enforcing supplier codes of conduct; 3) implement contractual agreements clearly outlining commitments and build relationships and trust through transparency. Establishing clear standards for practices would increase overall engagement and adherence to supply chain protocols. Contractual agreements and transparent communication are key points in solidifying commitment from all parties.
- SSC_4 (ineffective processes) - Recommended strategies: 1) streamline tendering and procurement protocols and automate ordering and approval workflows; 2) map and optimize workflows for efficiency standardize processes across locations; 3) simulate crisis scenarios and preparedness plans while negotiating contingency

capacity with key suppliers in advance; 4) conduct supplier market analysis and develop strategies to mitigate risk; 5) map end to end processes to identify integration gaps and standardize interfaces between parties; 6) invest in technologies like AI, IoT, blockchain to boost performance; 7) define clear roles and responsibilities while tracking individual performance and accountability; 8) develop and implement optimization models to streamline network design; 9) define quantitative metrics for supplier selection and performance management. Implementing these strategies would lead to achieve several advantages in terms of processing times, vulnerabilities, decision-making, operational performance, and accountability.

- IM_1 (inefficient distribution infrastructure) - Recommended strategy: implement digital inventory management systems. Digital inventory management systems aim to significantly improve the accuracy and efficiency of inventory tracking and order fulfillment, for a smoother distribution process and reduced stockouts.
- IM_3 (optimizing inventory for profit while averting shortages) - Recommended strategy: use demand forecasting and inventory optimization models, and increase safety stock. On the one hand, using demand forecasting and inventory optimization models would help in balancing inventory levels, thereby reducing shortages while maintaining profitability. On the other hand, increasing safety stock provides a buffer against unexpected demand spikes.

While implementing all these strategies simultaneously may pose challenges, establishing a roadmap for gradual implementation would allow healthcare organizations to focus on specific barriers and iteratively improve supply chain functions. This phased approach would mitigate the difficulties associated with simultaneous implementation by providing a structured path for continuous improvement. Prioritizing strategies based on their impact and feasibility would enable healthcare systems to navigate complexities while ensuring a resilient and optimized supply chain. Such a strategic mindset would certainly facilitate healthcare organizations in responding to supply chain challenges in a methodical way, enhancing collaboration, commitment, and process efficiency over time.

5. Conclusions

This research sheds light on the challenges faced by healthcare supply chains, especially emphasizing the critical need for robust supply chains to ensure a steady flow of essential medical resources. We herein proposes a FCM-based strategic model, incorporating fuzzy logic, to address uncertainties in supply chain management. Healthcare systems are indeed characterized by unique complexities. During crises, global healthcare supply chains face shortages and disruptions, where overreliance on single suppliers increases vulnerability and navigating global sourcing complexities demand regulatory compliance.

We led a deep literature aimed at identifying major supply chain factors, related barriers and recommended strategies. To manage the complexity of implementation, the study suggests a phased approach. The first phase involves highlighting the most significant factors, which appear to be supply chain complexity (SCC) and inventory management (IM). The second phase focuses on all of the related barriers, previously identified for the mentioned factors, which result to be lack of trust (SCC_2), lack of commitment (SCC_3), ineffective processes (SCC_4), inefficient distribution infrastructure (IM_1), and optimizing inventory for profit while adverting shortages (IM_3). This leads to the final recommendation of suitable strategies among the ones that are considered as mostly effective in the existing literature. For example, strategies like fostering trust in partnerships and incorporating advanced technologies are essential to overcome key barriers, including trust issues, commitment challenges, and inefficient processes. Furthermore, implementing advanced technologies, such as digital inventory management systems, enables more efficient tracking and control of inventory levels. The proposed approach aims to allow healthcare organizations to focus on specific barriers affecting main supply chain factors gradually, ensuring resilience while managing uncertainties and meeting the demands of patient care.

The main limitation of the framework herein proposed refers to the reliance on expert opinions when evaluating factors and barriers. Although this procedure provides valuable insights and context-specific knowledge, it may also limit the generalizability of the findings. On the one side, experts certainly bring a deep understanding of the operational challenges of healthcare supply chains, ensuring that the proposed strategies are well-grounded in practical realities. On the other hand, bias could be introduced, making it difficult to fully capture emerging trends or innovative practices outside the experts' experience.

Acknowledging this limitation, future research will focus on developing a detailed roadmap for the actual prioritization of strategies tailored to specific healthcare environments. This will include refinement of the proposed strategies within various real-world healthcare settings to validate their effectiveness, ensuring that interventions are contextually relevant and impactful. Additionally, we plan to integrate machine learning techniques to further enhance the model's predictive capabilities. Continuous monitoring based on feedback from implementation will be crucial for adapting to new challenges and ensuring the long-term resilience of healthcare supply chains.

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