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Prioritizing Agility Factors in IT–Enabled Healthcare Supply Chain under Uncertainty: A Joint ISM–MICMAC Approach

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The healthcare industry faces constant uncertainties, such as pandemics, regulatory changes, and demand fluctuations. This study is carried out to explore the key agility factors in IT–enabled healthcare supply chains and prioritize them to enhance the system's responsiveness and resilience in the face of uncertainty. To achieve the research objectives, a Joint Interpretive Structural Modelling (ISM) - MICMAC (Matrice d'Impacts Croisés Multiplication Appliquée á un Classment) approach is employed. The ISM methodology helps in developing a hierarchical model that elucidates the inter-relationships among various factors in the Healthcare Supply Chain (HSC). Through ISM, the factors are categorized as per their driving/dependence power. The study identified eleven such critical factors after conducting literature review along with expert's opinions. Organization Responsiveness occupies the highest hierarchical level and represents desired goals. To achieve these goals, continuous improvement of the lowest-level critical success factors is necessary, which can be achieved through critical examination and alternative solution generation. The subsequent MICMAC analysis further classifies these factors into autonomous, dependent, linkage, and independent categories, providing deeper insights into their impact and interdependencies. The model's hierarchy diagram indicates that 'Management commitment and support' is crucial factor. 'Organization Responsiveness' represents the top-level goals, achievable through continuous improvement of lower-level CSFs (Critical Success Factors) through critical examination and alternative solutions. The uniqueness of this research lies in its adoption of the Joint ISM-MICMAC approach to study Supply Chain Agility (SCA) factors in IT-enabled healthcare supply chains, yielding comprehensive insights beyond traditional analytical methods. Moreover, the focus on IT-enabled solutions adds novelty, considering the ongoing evolution of technology integration in healthcare supply chains.

Keywords: Agile supply chain, Decision-making, Interpretive structural modeling, MICMAC analysis, Performance evaluation

Introduction

The healthcare sector is one of the crucial sectors in the world today. The industry involves the production, distribution, and delivery of life-saving products and services, including medical devices, drugs, and other healthcare-related products.[1] To keep up with the fast-changing needs of consumers, healthcare providers must show agility in their operations.[2] However, uncertainties in the healthcare industry can make it challenging to maintain a high level of agility. This article will explore the concept of uncertain SCA in the healthcare industry and discuss some strategies that healthcare providers can use to overcome these challenges.

The capacity of healthcare professionals to promptly and efficiently address unexpected occurrences capable of causing disruptions in the supply chain.[3] These events can include natural disasters, pandemics, regulatory changes etc. that can disturb the production, distribution, and delivery of healthcare products and services.[4] The unpredictability of demand is a major challenge.[5] The demand for healthcare products and services can fluctuate significantly, making it difficult to forecast accurately. For instance, during a pandemic, the demand for Personal Protective Equipment (PPE) can increase exponentially, leading to shortages in supply.

Another challenge that healthcare providers face is the complexity.[6] Each stakeholder is important in the SC, and any disruption to one can affect the entire system.[7] As a result, healthcare providers must be able to work collaboratively with their supply chain partners.

To overcome the challenges associated with uncertain supply chain agility in the healthcare industry, healthcare providers can implement several strategies. Developing a contingency plan is one of the most effective ways to prepare for unforeseen events that can disrupt the supply chain.[8] Healthcare providers should identify potential risks and develop a plan to mitigate them. The contingency plan should

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include strategies for managing demand fluctuations, supplier disruptions, and other challenges that can arise.[9] Improving supply chain visibility is another essential strategy for overcoming uncertain supply chain agility. Healthcare providers should have real-time visibility into their supply chain to identify potential disruptions early on. This capability enables them to promptly adapt to shifts in demand and make necessary adjustments to their SC.[10] Healthcare providers can reduce the risk of supply chain disruptions by diversifying their suppliers. Healthcare providers should work with multiple suppliers to ensure that they have a backup plan if one supplier experiences a disruption. Technology plays a critical role in improving agility.[11] Healthcare providers ought to utilize technology to enhance visibility in the supply chain, automate processes, and minimize lead times. For instance, using a cloud-based supply chain management system can help healthcare providers improve collaboration with their supply chain partners and streamline their operations.

Building a resilient supply chain is essential for healthcare providers looking to overcome uncertain SCA. A resilient SC can withstand disruptions and adapt to changes in demand.[12,13]

Why Interpretive Structural Modelling?

Interpretive Structural Modeling (ISM) is a methodology that facilitates the creation of a hierarchical model illustrating the interconnections among different factors within a complex system. The technique was first proposed by Warfield[14] and has since been used in numerous applications. The process involves a series of steps that help to identify the relationships between different elements of the system, and to identify the most important elements that affect the system's overall performance. ISM has been used in various domains to analyse complex systems. One of the key benefits of using ISM is that it can help researchers to identify the key drivers of a system's performance. Through the identification of these drivers, researchers can gain a deeper understanding of the factors that play a crucial role in determining the overall performance of a system. Recent studies have demonstrated the utility of ISM in a range of domains.[15–17]

Research Gap

The literature contains applications of ISM–MICMAC analysis; however, the absence of a ranking for factors driving agility in the IT-enabled domain is a gap in current research. Given the diverse identification of significant factors in each study, it becomes crucial to establish relationships between these factors. Consequently, the aim of this paper is to employ ISM to prioritize factors influencing uncertain supply chain agility in the healthcare industry and to construct a structural model.

Factor Identification

To determine the factors, a literature review was carried out. In this review, approximately 20 factors were pinpointed. A group of eight experts, consisting of five academic professionals and three industry experts, engaged in a hybrid mode discussion. This collaborative effort resulted in the identification of eleven pertinent Critical Factors (CFs) for this research. The elimination of factors was carried out through a rigorous critical examination technique, carefully considering the significance of each factor.

Recognition of Need for Agility

Attaining supply chain agility necessitates the acknowledgment of distinctive attributes, encompassing factors like demand variability, supplier relationships, inventory management, and transportation, among others. By understanding these factors, organizations can better prepare to respond to changes and disruptions, such as unexpected changes in demand, supply chain disruptions, and regulatory changes.[18] Therefore, to successfully embrace the agile paradigm in the supply chain, organizations must be proactive and agile in their approach, to identify areas for improvement and adjustment. They must also prioritize collaboration and communication with suppliers and other partners in the supply chain to promote greater transparency, trust, and responsiveness.[19]

Integration of Agility into the Strategic Context

It involves setting goals and objectives that prioritize responsiveness, flexibility, and adaptability.[20] It is also necessary to develop SC operation strategies that prioritize agility[21], such as just-in-time inventory management, flexible manufacturing processes, and agile transportation and logistics capabilities. Additionally, supply chain strategic decisions, such as sourcing strategies, must be aligned with the organization's goals. Facilitating this entails fostering collaboration and communication throughout the SC, promoting transparency, trust, and alignment toward the common objective of achieving SCA.[22]

Management Commitment and Support

Firstly, organizations must recognize the value of SCA.[23] This requires a clear understanding of the benefits of agility, such as improved customer satisfaction, increased profitability, and reduced lead times. Secondly, organizations must provide the necessary technical and financial support to achieve supply chain agility. This may involve investing in new technology, such as automated inventory management systems, or providing training and resources to employees to promote agility.[24] Finally, creating a culture that supports agility is critical to achieving supply chain agility.[25]

Internal Collaboration

Inter-functional and inter-departmental integration involves breaking down silos within the organization and promoting collaboration and coordination between different functional areas and departments.[26] This requires a willingness to share information, resources, and knowledge across organizational boundaries. Establishing synergistic and cohesive relationships between organizational units is also critical.[27] This requires a focus on building trust and mutual respect between different departments and functional areas, as well as a willingness to work together to achieve shared goals and objectives. Cross-functional alignment is also crucial to achieving supply chain agility. This involves aligning different functional areas and departments around a shared goal of agility and ensuring that everyone is working towards that goal.[28] This necessitates a culture that encourages experimentation, learning, and innovation, as well as a focus on collaboration and teamwork to achieve shared objectives.

Relationship with Partners/Suppliers

This requires a focus on working closely with partners to identify and address challenges and opportunities, goals.[29] Synchronized supply is also critical to achieving supply chain agility.[30] Establishing relationship requires a focus on building trust and mutual respect, as well as a willingness to invest in the relationship over the long term. This involves regular communication, joint problem-solving, and a commitment to shared goals and objectives.[31]

Information Flow within the Supply Chain

Transparency across the supply chain is also crucial to achieving agility.[32] To achieve this, organizations must prioritize collecting, analyzing, and disseminating data that is useful and relevant to all partners in the supply chain. They must also break down information silos within the organization and promote collaboration and coordination between different functional areas and departments.

Efforts for Supply Chain Monitoring

Organizations must monitor changes in competition patterns and customers' requirements and be prepared to adjust their supply chain operations accordingly.[33] They must also be aware of changes in supply sources and potential disruptions to the supply chain. Organizations must develop robust systems for monitoring and detecting potential issues. By being proactive and responsive, organizations can achieve greater agility and gain a competitive advantage.[34,35]

IT Infrastructure and Support

To facilitate communication and information flows and improve supply chain agility, organizations can leverage Information and Communication Technologies (ICT). This involves using ICT to enable seamless communication and information exchange.[36] IT integration and flexibility are also crucial. This involves using technology to streamline processes, improve efficiency, and reduce lead times, making it easier for organizations to respond.[37] By leveraging ICT and computer-assisted technologies, organizations can enhance the agility. Adoption of advanced information technology, such as electronic health records and automated inventory management systems along with IoT adoption can enable better visibility and responsiveness throughout the healthcare supply chain.

Organization Responsiveness

Attaining supply chain agility necessitates organizations to promptly and cost-effectively adapt to market changes. This entails recognizing opportunities for enhancement and actively collaborating across business units and entities to tackle potential issues. Additionally, active involvement in strategy development and planning is essential to align the supply chain with overarching business goals and objectives.[38] Proficiency in change management is equally vital for achieving supply chain agility, as organizations must adeptly handle supply chain resources and promptly react to shifts in the market and broader business landscape.[39]

Competence of Human Resources

This entails ensuring that employees comprehend the goals and objectives of the supply chain and are dedicated to its implementation.[40] Employees need to swiftly adapt to market changes and the broader business environment, fostering collaboration across business units and organizations to address potential issues. Moreover, employees should have the empowerment to make decisions and take responsive actions.[41] This necessitates furnishing employees with the requisite training and resources to support their roles in the supply chain. Establishing a culture of agility and ensuring full engagement and commitment from employees towards the supply chain's goals and objectives enable organizations to attain heightened agility and secure a competitive advantage in the market.

Culture for Continual Improvement

To achieve this, organizations must minimize resistance to change and be open to accepting new ideas.[42,43] By adopting a culture of continuous improvement and a willingness to learn and adapt, organizations can improve the flexibility and responsiveness. It will allow them to meet customer requirements more effectively, respond quickly, and gain a competitive advantage in the market.

Methodology

The ISM approach operates under the assumption that the elements within a system are interconnected, and their relationships can be represented as a hierarchical structure of levels.[18] Each level represents a set of components that are related to each other and have a similar level of importance within the system. The components at the top of the hierarchy are the most important, while those at the bottom are the least important.

The construction of a logical mental diagram involves a systematic procedure. It is illustrated in the following steps:

1. Identify factors that are relevant to the specific problem through an extensive literature survey. Suggestions from practicing professionals are taken for finalizing the final list of factors.
2. Form relationships among the finalized contributing factors.
3. Develop a Structural Self-Interaction Matrix (SSIM)
4. By employing SSIM, a reachability matrix was created and examined for any concerns related to transitivity. The term 'Transitivity' refers to dependence of one factor over another and another factor over many more factors. So the first factor in consideration will indirectly influence the other dependent factors.
5. Level Partitioning
6. Prepare a directed graph.
7. For the ISM model
8. Due to the complex structure of the problem, conceptual inconsistencies may arise. Therefore, reviewing is necessary to identify and make any necessary modifications to the ISM.

SSIM

The perspectives of experts were gathered to delineate relationships among the considered factors. A user-friendly interface was created for the purpose of data collection, prompting experts to assess the relationship between a single factor and another by selecting one of four buttons. These relationships underwent analysis employing four variables, aiming to discern the directional connection between the two factors (i and j) in SSIM development. The determination of the relationship direction between two factors (i and j) in SSIM development relies on the interpretation of four variables: 'V,' denoting that the i^{th} factor endeavors to attain the j^{th} factor; 'A,' indicating that the j^{th} factor endeavors to attain the i^{th} factor; 'X,' signifying mutual enhancement between factors i and j; and 'O,' representing no discernible relation between the factors. The conclusive SSIM matrix, as illustrated in Table 1, was then formulated based on these analyses.

Reachability Matrix

In the process of transforming SSIM into the Reachability Matrix (RM), the symbols V, A, X, and O were systematically replaced with binary values, 1 or 0, based on specific conditions. This substitution adhered to distinct rules: if the SSIM value denoted 'V' (indicating that the i^{th} factor endeavors to attain the j^{th} factor), the corresponding cells in RM were set to 1 and 0 for the i^{th} and j^{th} factors, respectively. Conversely, if the SSIM value indicated 'A' (representing that the j^{th} factor aims to attain the i^{th} factor), the respective cells in the RM were set to 0 and 1. In the case of 'X' denoting mutual enhancement between factors i and j, both corresponding cells were set to 1. Finally, if 'O' signified no discernible relation, both cells were set to 0. The initial reachability matrix (IRM) was established and presented in Table 2. Subsequently, the final reachability matrix was generated eliminating transitive relationships, as depicted in Table 3, where row-wise summation provides driving power and column-wise summation provides dependence power of the factor in consideration.

Table 1 — Structural self-interaction matrix (SSIM)

FN	Factors/problems	1	2	3	4	5	6	7	8	9	10	11
1	Recognition of need for agility	—	V	A	O	O	O	V	O	V	V	O
2	Integration of agility into the strategic context		—	A	V	V	V	V	O	O	O	V
3	Management commitment and support			—	V	V	V	V	V	V	V	V
4	Internal collaboration				—	O	V	V	O	V	O	V
5	Relationship with partners/suppliers					—	V	O	O	O	O	A
6	Information flow within the supply chain						—	V	A	V	O	O
7	Efforts for supply chain monitoring							—	A	V	O	O
8	IT infrastructure and support								—	V	O	O
9	Organization responsiveness									—	A	A
10	Competence of human resources										—	V
11	Culture for continual improvement											—

Table 2 — Initial reachability matrix (IRM)

FN	1	2	3	4	5	6	7	8	9	10	11	DR.P.
1	1	1	0	0	0	0	1	0	1	1	0	5
2	0	1	0	1	1	1	1	0	0	0	1	6
3	1	1	1	1	1	1	1	1	1	1	1	11
4	0	0	0	1	0	1	1	0	1	0	1	5
5	0	0	0	0	1	1	0	0	0	0	0	2
6	0	0	0	0	0	1	1	0	1	0	0	3
7	0	0	0	0	0	0	1	0	1	0	0	2
8	0	0	0	0	0	1	1	1	1	0	0	4
9	0	0	0	0	0	0	0	0	1	0	0	1
10	0	0	0	0	0	0	0	0	1	1	1	3
11	0	0	0	0	1	0	0	0	1	0	1	3
	2	3	1	3	4	6	7	2	9	3	5	45

Table 3 — Final Reachability matrix

FN	1	2	3	4	5	6	7	8	9	10	11	DR.P.
1	1	1	0	1	1	1	1	0	1	1	1	9
2	0	1	0	1	1	1	1	0	1	0	1	7
3	1	1	1	1	1	1	1	1	1	1	1	11
4	0	0	0	1	1	1	1	0	1	0	1	6
5	0	0	0	0	1	1	1	0	1	0	0	4
6	0	0	0	0	0	1	1	0	1	0	0	3
7	0	0	0	0	0	0	1	0	1	0	0	2
8	0	0	0	0	0	1	1	1	1	0	0	4
9	0	0	0	0	0	0	0	0	1	0	0	1
10	0	0	0	0	1	0	0	0	1	1	1	4
11	0	0	0	0	1	1	0	0	1	0	1	4
	2	3	1	4	7	8	8	2	11	3	6	55

Table 4 — Level Partitioning

FN	Reachability set	Antecedent set	Level
1	1,2,4,5,6,7,9,10,11	1,3	VIII
2	2,4,5,6,7,9,11	1,2,3	VII
3	1,2,3,4,5,6,7,8,9,10,11	3	IX
4	4,5,6,7,9,11	1,2,3,4	VI
5	5,6,7,9	1,2,3,4,5,10,11	IV
6	6,7,9	1,2,3,4,5,6,8,11	III
7	7,9	1,2,3,4,5,6,7,8	II
8	6,7,8,9	3,8	IV
9	9	1,2,3,4,5,6,7,8,9,10,11	I
10	5,9,10,11	1,3,10	VI
11	5,6,9,11	1,2,3,4,10,11	V

Level Partitions

The establishment of the reachability set involved identifying instances where there was a '1' in the i^{th} row, while the antecedent set was formulated by detecting '1' in the j^{th} column. The matching factors in reachability set and antecedent set were then computed to derive the intersection set. This set, representing shared elements across factors, was pivotal in determining levels. Specifically, the i^{th} factor, possessing similar elements in the reachability and intersection sets, was assigned to a designated level, denoted as Level I. Subsequently, the i^{th} factor was excluded, and the intersection set was recalculated through a repeated process until all factors were appropriately assigned to distinct levels. The inaugural iteration of this level partitioning is exemplified as Level I in Table 4. These designated levels are important in the construction of the diagram and the final ISM model.

Formation of ISM

The data in Table 4 contain the level partition tables used to generate the ISM (Fig. 1). All the factors are joined as per their relationship with the other factor.

MICMAC Analysis

MICMAC analysis is a strategic management tool designed for assessing the interrelationships among a set of variables or factors. Frequently applied in strategic planning, marketing, and environmental management, MICMAC helps decision-makers understand the dynamics within a system by categorizing factors into those with high driving power and those with high dependence. The MICMAC is illustrated in Fig. 2.

Results and Discussion

ISM serves as a method for the comprehensive analysis and modeling of intricate systems, offering a framework to construct a hierarchical structure that delineates relationships among diverse system components or factors. This facilitates a deeper comprehension of the system's dynamics and the interactions among its elements. The versatility and user-friendly nature of ISM make it adaptable to various interdisciplinary teams, fostering collaboration and handling the complexities inherent in intricate systems. The methodology involves pair wise comparisons to generate a reachability matrix, revealing driving and dependent factors within the system.

To address the challenges of prioritizing factors within an organization, this study employed the ISM methodology and MICMAC analysis in the healthcare sector, with the aim of enhancing performance. Following an extensive literature review, eleven factors were identified to form the ISM model. The Reachability Matrix in Table 3, without transitivity, accounts for driving and dependence power. Factors with the highest driving power, such as 'Management commitment and support', and 'Recognition of Need' exert a substantial influence on other system factors, suggesting that improving these factors can positively impact overall system performance.

In Table 5, Table 6, and Fig. 2, 'IT Infrastructure and Support' and 'Competence of Human resources' are situated in Cluster I, representing autonomous factors. Cluster II encompasses critical success factors like 'Relationship with Partners/Suppliers', 'Information flow within the supply chain', 'Efforts for supply chain monitoring', 'Organization Responsiveness', and 'Culture for Continual improvement', characterized as dependent factors. Notably, no factors fall within Cluster III, indicative of a stable system unaffected by external factors. The remaining factors, including

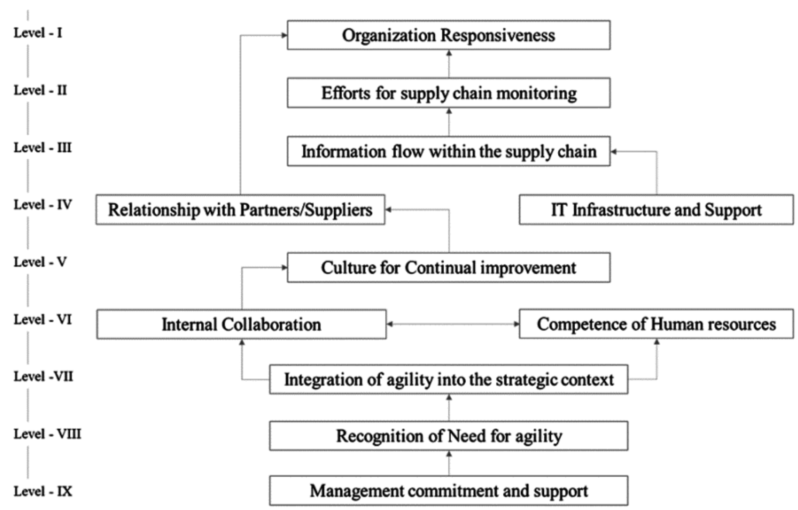

Fig. 1 — ISM Model

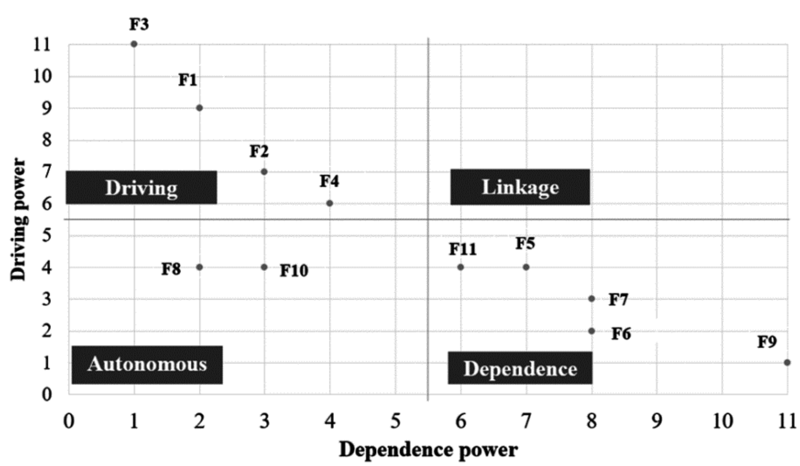

Fig. 2 — MICMAC analysis

Table 5 — MICMAC ranking of the factors

Factor	Dependence power	Driving Power	Driving/ Dependence power	MICMAC Rank
1	2	9	4.50	2
2	3	7	2.33	3
3	1	11	11.00	1
4	4	6	1.50	5
5	7	4	0.57	8
6	8	3	0.38	9
7	8	2	0.25	10
8	2	4	2.00	4
9	11	1	0.09	11
10	3	4	1.33	6
11	6	4	0.67	7

Table 6 — Cluster formation as per IRM

Cluster No	Clusters	Factors
I	Autonomous	8, 10
II	Dependence	5,6,7,9,11
III	Linkage	—
IV	Driving	1,2,3,4

'Management commitment and support', and 'Internal Collaboration', are grouped in Cluster IV as driving factors. The considerable driving power of these critical success factors, coupled with limited dependence, underscores their pivotal role in achieving substantial improvements in the current system, suggesting that policymakers and software developers should prioritize addressing these factors for enhanced system performance.

The eleven factors were ranked using a simple formula that divides a factor's driving power by its dependence power. A higher ranking is achieved with more driving power and less dependence. Table 5 displays the rankings after the MICMAC analysis.

The investigation focused on the modeling of enablers for supply chain agility using ISM, with a specific emphasis on the automotive sector.[44] Various factors associated with modeling and analyzing factors in healthcare organizations were taken into account in the study.[45] The study proposed a composite model integrating AHP and ISM methodologies to evaluate the agility of the supply chain.[46]

Managerial Implications

Managers can use the identified critical factors, especially 'Management commitment and support,' to inform strategic decisions. Prioritizing these factors can guide the development of agile strategies. Policymakers can focus on creating policies that support and enhance the key factors identified in the study. Regulations can be tailored to encourage management commitment, technological integration, and organizational responsiveness, fostering a conducive environment for agile healthcare supply chains. Understanding the hierarchy of critical success factors enables efficient resource allocation. Managers can allocate resources and investments towards factors that are identified as most crucial, ensuring maximum impact on the supply chain's agility.

Conclusions

This study is done to determine the influencing factors and formulate an interpretive structural model of eleven factors for evaluating agility of supply chain in healthcare sector. The proposed model effectively displays the interrelationships among these CSFs (Critical Success Factors) and can aid decision makers in understanding their relative importance for effective supply chain planning. Based on the model's hierarchy diagram, the 'Management commitment and support' CSF is the most important as it drives other CSFs and aids in strategic planning. It is recommended that policy makers and management authorities to prioritize policies and organizational structure to improve supply chain agility. The CSFs such as Organization Responsiveness occupy the highest hierarchical level and represent desired goals. To achieve these goals, continuous improvement of the lowest–level CSFs is necessary, which can be achieved through critical examination and alternative solution generation. The research heavily relies on existing literature and expert opinions. Limited data availability or biased sources could impact the accuracy and comprehensiveness of the identified critical factors. Technology in healthcare is constantly evolving. The agility factors identified might become obsolete or less relevant due to rapid technological advancements.

Future research could compare agility factors across various industries to identify commonalities and industry-specific nuances. Understanding different sectors' agility strategies could provide a broader perspective for healthcare supply chains. Conducting longitudinal studies can track the evolving nature of agility factors over time. This approach would capture changes in technology, regulations, and market demands, offering insights into the adaptability of healthcare supply chains. Given the rapid evolution of technology, ongoing research could explore emerging IT solutions, like block chain, artificial intelligence, and IoT devices, and their impact. This would ensure that the study remains relevant in the face of technological advancements.

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