

Strengthening healthcare supply chains: a social–ecological perspective on resilience

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Abstract

Purpose – This paper aims to contextualise the resilience of the healthcare supply chain (HSC) from a social–ecological (S–E) perspective, with the dual aim of investigating S–E resilience principles reflected in HSC resilience literature and identifying actions and barriers that affect HSC’s capabilities to persist, adapt and transform in response to disturbances. In doing so, the study addresses the fragmentation in current conceptualisations of HSC resilience.

Design/methodology/approach – A contextualised literature review systematically analysing a corpus of 89 peer-reviewed articles, guided by a S–E resilience framework, was employed to identify key actions, barriers and applied resilience principles in the HSC context.

Findings – Key S–E resilience elements, such as collaboration, flexibility and agility, are already present in the HSC resilience literature. Actions enhancing HSC resilience were identified and categorised by implementation phase and enabled S–E resilience capability. Most resilience actions align with persistence and adaptation; only a few cases of transformative resilience are documented. The identification of contextual factors, such as regulatory rigidity, resource constraints and fragmentation, hindering adaptation and transformation, as well as progress towards a desirable post-disturbance state, is another key finding of this study.

Social implications – Enhancing these capabilities improves the system’s ability to withstand and recover from disturbances, ensuring continuous access to healthcare services, and allows the HSC to transform, exploiting disturbances as opportunities to evolve to a new, better post-disturbance state. Such transformation can lead to more equitable healthcare delivery, reduce vulnerabilities and improve long-term outcomes.

Originality/value – This study examines HSC resilience through the lens of S–E resilience, which emphasises transformation to a stronger state after disturbances rather than merely restoring stability, overcoming the engineering resilience conceptualisation.

Keywords Healthcare supply chain, Social–ecological resilience, Resilience principles, Resilience actions, Transformative resilience

Paper type Literature review

1. Introduction

The healthcare supply chain (HSC) is a complex network of organisations providing healthcare products and services required for treating and managing acute or chronic diseases (Senna *et al.*, 2023). In this context, where well-being, health, or even lives are at stake (Aldrighetti *et al.*, 2019; Scala and Lindsay, 2021), effective HSC management is paramount. Although HSCs share similarities with other supply chains, they require tailored approaches to guarantee effective operations and continuity of care (de Vries and Huijsman, 2011). Additionally, over the next decades, HSCs will need to adapt and evolve to effectively provide healthcare services to a growing elderly population in increasingly volatile contexts (Samani *et al.*, 2020; Senna *et al.*, 2023), reaching new quality and robustness levels while reducing costs. Therefore, although the efficiency of the HSC is a primary goal for managers and



policymakers, it is even more important to ensure the continuity of operations, so that healthcare services and products can be guaranteed for all patients in need under every condition (Almeida, 2024).

To maintain continuity, the HSC must be able to withstand *disturbances*, ranging from *high-frequency-low-impact* disturbances – such as suppliers' delays, quality issues and general services interruptions – to *low-frequency-high-impact* disturbances – such as pandemics, earthquakes, floods, famine and wars (Chopra *et al.*, 2007; Ivanov, 2021; Oke and Gopalakrishnan, 2009; Tang, 2006). To ensure the continuity of healthcare operations and services, *HSC resilience*, interpreted as “the capability of the supply chain to provide uninterrupted treatments and healthcare products to patients in the event of a disturbance, consequently maintaining continuity of operations” (Mandal, 2017), is paramount. Yet, this interpretation of the resilience concept is limited, as it fails to recognise disturbances as an opportunity for transforming to a more desirable state than the original one (Davoudi *et al.*, 2013; Hohenstein *et al.*, 2015; Scala and Lindsay, 2021). Including such a transformative dimension aligns the definition of resilience to the social–ecological (S–E) perspective of resilience as discussed in Wieland and Durach (2021), where supply chain resilience is defined as the capacity of a supply chain to persist, adapt and *transform* in the face of change.

Resilience in the S–E sense can be achieved through initiatives, efforts and interventions – collectively referred to in this paper as *resilience actions* – designed to enhance the HSC's capabilities to persist, adapt and transform. These actions can be implemented either before or after a disturbance occurs (Ali *et al.*, 2017): in the former case, the actions focus on preparing for possible future disturbances (*pre-disturbances actions*), whereas in the latter, they adjust processes and structures after a disturbance (*post-disturbances actions*) (Ivanov *et al.*, 2017). The effectiveness of these actions is influenced by potential *barriers*, that is, context-specific elements that may hinder the achievement of HSC resilience. Furthermore, the concept of supply chain resilience, as viewed from the standpoint of S–E systems, can be bolstered by seven fundamental *principles* (Biggs *et al.*, 2012). These were identified in the context of management and governance within intertwined systems of people and nature and were contextualised to the supply chain literature by Wieland *et al.* (2023).

HSC resilience is an evolving and still-developing area of research, as reflected in the literature's inconsistent use of terminology (Scala and Lindsay, 2021). Studies have primarily focused on specific healthcare segments, such as pharmaceuticals (Golan *et al.*, 2021) and personal protective equipment (Cuvero *et al.*, 2021), resulting in fragmentation and a lack of consensus and unanimity among scholars. Additionally, in the HSC resilience literature, barriers have received less attention compared to actions (Ganguly and Farr, 2023).

Therefore, given the relevance of HSCs, the lack of a homogeneous perspective on the topic and the interpretative power of the S–E perspective as a theoretical lens, this study aims to contextualise S–E resilience within the HSC context. Particular attention is given to S–E resilience principles, introduced in detail in Section 2.3, that can be discerned intuitively in the HSC resilience literature. The RQs guiding the research are:

- RQ1. What social-ecological resilience principles have been applied to address the unique challenges of the HSC to promote social-ecological resilience?
- RQ2. Which actions and barriers influence the development of persistence, adaptation and transformation capabilities for social-ecological resilience in the HSC?

The paper conducts a contextualised literature review (CLR) beginning with an initial theoretical framework (Section 2). Section 3 details the CLR protocol, followed by a descriptive analysis (Section 4) illustrating the essential research elements required to answer the research questions. Sections 5 and 6 present the findings and insights that answer the research questions. Then, the discussion and future research avenues are presented (Section 7). Finally, theoretical and managerial implications are reported, and the research conclusions are summarised (Section 8).

2. Research background

2.1 The healthcare supply chain

The HSC is a network of organisations involved in manufacturing, distribution and provision of healthcare products (i.e. drugs, medical equipment) and services (Dobrzykowski, 2019; Pinna *et al.*, 2015; Rakovska and Stratieva, 2018; Senna *et al.*, 2023). While sharing core principles with supply chains in manufacturing and service industries, it stands out for its unique characteristics, which often require tailored approaches (de Vries and Huijsman, 2011). The HSC is characterised by objectives beyond profit, such as treating diseases and improving health (Senna *et al.*, 2023). Consequently, HSC has significant social impact and ethical responsibility, as its reliability and stability directly affect public health in regulated settings (Hussain *et al.*, 2018; Furstenau *et al.*, 2022).

HSC healthcare products and services are highly personalised and tailored to individual needs (Minvielle *et al.*, 2014). Often, patients do not actively choose them but need them for medical necessity, making demand unpredictable and difficult to control (Dobrzykowski, 2019). Additionally, many healthcare products are costly, complex and require special handling (Rakovska and Stratieva, 2018).

Because of its critical flows, the HSC must have a very high service level, close to 100% (Aldrighetti *et al.*, 2019), making operational continuity essential. Enhancing HSC resilience improves disturbance management, boosts performance (Senna *et al.*, 2023) and benefits organisations by ensuring ongoing operations (Ali *et al.*, 2017). Ignoring these factors can pose major risks to the entire HSC (Aigbogun, 2023).

Given these characteristics, the HSC can be viewed as a social–ecological system, that is, a complex adaptive system (CAS) where social and technical aspects are closely linked (Redman *et al.*, 2004; Wieland, 2021). This interpretation challenges the traditional, engineerable perspective often applied to HSC resilience and instead advocates for a socio-ecological approach that accepts transformation.

2.2 Social-ecological supply chain resilience

Resilience, first studied in social sciences, describes how communities, institutions and economies respond to disturbances (Ponomarov and Holcomb, 2009). While its meaning varies across fields, resilience is often defined as an element's ability to withstand disturbances and return to stability (Bhamra *et al.*, 2011; Ivanov *et al.*, 2017). This aligns with engineering resilience, which aims to minimise disturbance impacts and quickly return to the previous state (Holling, 1996). The S–E view expands on this, focusing on transitions to a better post-disturbance state and viewing resilience as the ability to reorganise and seize opportunities from disturbances (Holling, 1996; Wieland and Durach, 2021).

The S–E resilience perspective is not yet common in supply chain resilience studies and is largely unexplored in the HSC resilience literature, yet it offers benefits. An engineering resilience view may oversimplify HSCs, focusing only on quick recovery to the pre-disturbance state. In contrast, the S–E perspective better suits HSCs as CASs (Redman *et al.*, 2004; Wieland, 2021), emphasising transformation, adaptability and persistence for long-term resilience.

2.3 Theoretical framework

S–E resilience is linked to three capabilities (Wieland *et al.*, 2023): *persistence* (the ability to withstand adverse events without operational interruptions (Araujo *et al.*, 2022; Chowdhury *et al.*, 2024)), *adaptation* (the ability to adjust the system in response to actual or expected changes, ensuring operational continuity during disturbances (Shweta *et al.*, 2022; Vann Yaroson *et al.*, 2023a)), and *transformation* (the ability to transform the system's structure and process more radically in response to changing conditions or disturbances (Wieland *et al.*, 2023)). These three capabilities are not mutually exclusive and may be used sequentially or simultaneously.

In the literature, the adaptive cycle – a model describing complex systems with four phases: (1) conservation with resource buildup; (2) release following disturbances; (3) reorganisation as the supply chain adapts; and (4) exploiting the new state (Holling, 1987; Wieland, 2021) – has been used to explain the concept of S–E resilience and, consequently, the three resilience capabilities (Holling, 1986). The S–E resilience capabilities are related to different phases of the adaptive cycle. In the conservation phase, typically characterised by persistence as the system strives to maintain its core functions and structure despite emerging pressures, efficiency, stability and optimisation are prioritised through pre-disturbance actions. A disturbance may precipitate the transition from the conservation to the release phase (Wieland, 2021), in which post-disturbance action can be implemented to respond to the disturbance. Post-disturbance action can favour the transition from release to the reorganisation phase. If this transition is achieved thanks to small, gradual changes, it favours adaptation capability. More profound and radical changes, pushing the transition from release to reorganisation, are associated with transformation capabilities involving significant changes in structure, processes, or governance. Adaptation and transformation can enable the system to reach a new, more resilient state during the subsequent exploitation phase, thus initiating a new cycle of growth and development (Wieland *et al.*, 2023) (Figure 1).

The concept of supply chain resilience, as viewed from the standpoint of S–E systems, can be bolstered by seven fundamental principles (Biggs *et al.*, 2012; Wieland *et al.*, 2023). The following overview highlights the main principles that inform the concept of supply chain resilience, serving as reference points for understanding its application in HSCs. The first of these highlights the importance of diversity and redundancy, which enable SCs to adapt to change. The second principle pertains to the management of connectivity, underscoring that while a well-connected SC can expedite recovery from disturbances, an excess of connectivity can amplify the propagation of crises. The third principle emphasises the importance of monitoring slow variables and providing feedback, as gradual changes can lead to irreversible transformations if not addressed promptly. Principles four and five advocate complex adaptive systems thinking and encourage learning, both of which are essential for dealing with uncertainty and improving adaptability. Finally, principles six and seven emphasise the importance of broadening participation and adopting polycentric governance, with multiple autonomous and flexible decision-making entities, to ensure effective and resilient management (see Wieland *et al.* (2023) for details).

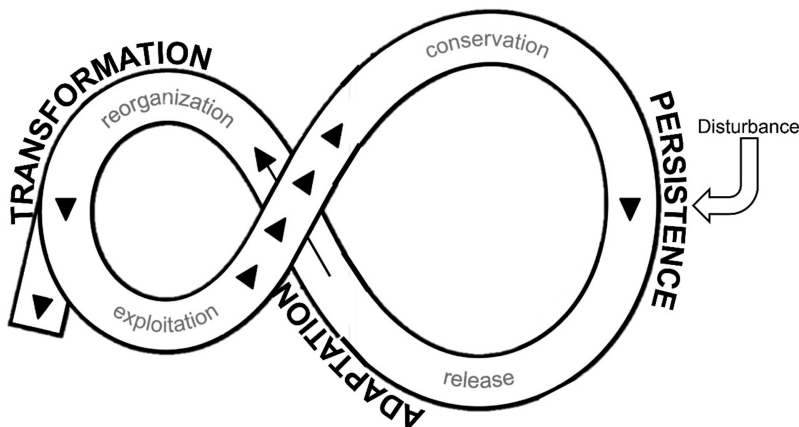


Figure 1. Supply chain resilience adaptive cycle. Adapted from Holling (1986) and Wieland and Durach (2021)

The adaptive cycle has been instrumental to developing and refining the research questions addressed in this study, and informing the subsequent CLR (Durach *et al.*, 2021), as the three capabilities, persistence, adaptation and transformation, provided a conceptual lens to distinguish how HSCs respond to disturbances and evolve towards a new, better post-disturbance state.

3. Methodology

We opted for a CLR that helps create or improve our knowledge of “for whom,” “in what circumstances,” and “when” certain phenomena can be observed (Durach *et al.*, 2021). The phenomenon under observation is thus the development of S–E resilience in HSCs, as influenced by specific resilience actions and hindered by contextual barriers. Furthermore, the CLR examines to what extent the principles of S–E resilience have already been applied within the HSC context to address its unique challenges. The “for whom” dimension is focused on the point of care delivery to patients. The “in what circumstances” element considers the type of disturbance. The “when” dimension distinguishes between pre-disruption and post-disruption, which maps directly onto the timing of resilience actions and into the resilience capabilities of persistence, adaptation and transformation. The CLR followed a systematic approach (Tranfield *et al.*, 2003) and was conducted in accordance with guidelines for systematic literature reviews in supply chain management (Durach *et al.*, 2017; Sauer and Seuring, 2023). A detailed description is provided in Figure 2.

While our review encompasses both healthcare product and service supply chains within the broader HSC context, our unit of analysis is defined more narrowly: we focus on supply chain disturbances, whether originating in the product or service domain, that directly affect the continuity of care at the point of delivery to patients. This framing reflects the strong interdependence between product and service flows in healthcare delivery and allows us to analyse resilience at the level of care provision rather than at the level of isolated supply chain segments.

Based on a discussion among the authors, the inclusion and exclusion criteria have been defined considering the research questions (content-related criteria) and the expected quality of the primary studies (quality-related criteria). The relevant literature was identified by defining the keyword used to build a search string, finding key articles that provided background information on supply chain resilience and reviewing the references used to determine a list of articles as complete as possible, keeping the number of irrelevant hits as low as possible, following general guidelines (Tranfield *et al.*, 2003). The selected keywords included multiple synonyms to obtain a broad baseline sample and were combined using Boolean operators to construct the search string (reported in Table 1).

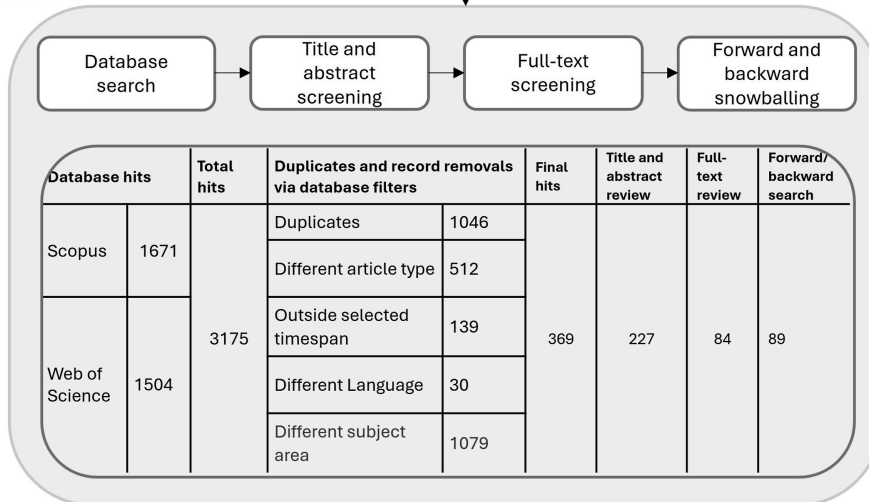
The inclusion/exclusion criteria, presented in Figure 2, were applied to reduce the number of papers in line with guidelines for systematic literature reviews on supply chains (Sauer and Seuring, 2023). Each author independently reviewed each title and abstract, selecting those that met the inclusion criteria. Disagreements over paper inclusion were resolved through discussion till a consensus among the authors was reached. Finally, a citation analysis was used to complement the article search and identify additional relevant works not found with the initial database search (Wohlin, 2014). Figure 2 provides a detailed illustration of the selection process and the rationale behind excluding certain papers. The complete list of references is available as supplementary material (S1).

Following the recommendations set out in the literature (Durach *et al.*, 2017), to ensure the alignment of the analysis with the CLR’s objective (Schorsch *et al.*, 2017), the research questions were used to determine which data to extract and to define an *a priori* coding structure, presented in supplementary material S2. As illustrated in Figure 2, open coding, representing the initial stage of abstraction, enabled the extraction of concepts in each category in their original form. Given the diversity of the intervention mechanisms considered, integrating and synthesising the collected concepts was necessary, grouping them into

INCLUSION CRITERIA

- Definition of the required characteristics of primary study:
- The time interval must be between 2014-2025 for journals and 2021-2025 for conferences;
- The abstract must show a clear indication of actions, barriers, and principles (or their synonyms);
- Papers must address resilience, not only resilience-related concepts

PAPER SELECTION



PAPER ANALYSIS AND SYNTHESIS

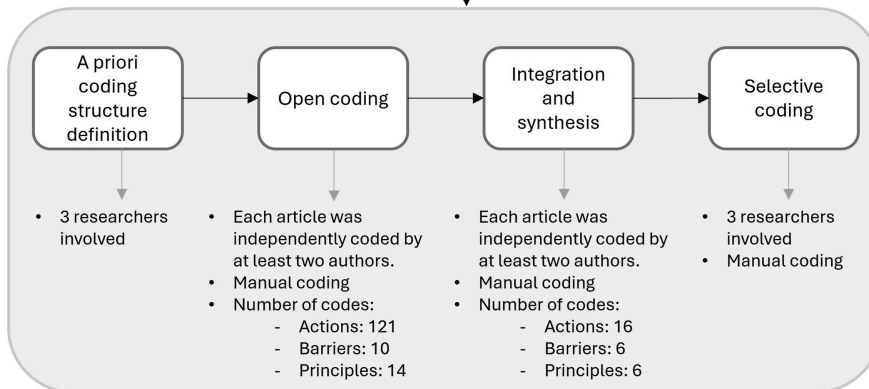


Figure 2. Literature review methodology overview

subcategories (see [Appendix Tables A1, A2, and A3](#)). Concepts that could not be aggregated with others were treated as singular actions, principles, or barriers. Finally, codes were related to one another, revealing connections and relationships among concepts. The synthesis of the codified information thus enabled greater abstraction of the framework ([Durach et al., 2015](#)), facilitating an understanding of the relevant factors influencing HSC resilience. In the selective coding phase, resilience capabilities served as an analytical framework for coding the resilience

Table 1. Keywords and search string

Resilience	Supply chain	Healthcare	Actions, barriers, principles
Resilien*	AND “supply chain” OR supply-chain OR logistic*	AND healthcare OR medical OR health-care OR health OR “primary care” OR nhs OR “nursing care” OR pharmac* OR “national healthcare service” OR “hospital care” OR “inpatient care” OR “outpatient care”	AND Formative element* OR strateg* OR dimension* OR antecedent* OR measurement* OR action* OR element* OR attribute* OR enabler* OR principle* OR mediator* OR barrier* OR challenge*

actions identified in the literature. Actions were interpreted in terms of which capability they supported. This approach allowed to link resilience actions to S–E resilience capabilities and, ultimately, to the post-disturbance state they enabled (whether previous status quo or a new, better post-disturbance state). These capabilities were not explicitly coded during the earlier rounds, as they were not directly reported in the reviewed papers, but their application in the selective coding helped contextualise the S–E resilience within the HSC context.

4. Descriptive results

The descriptive analysis in this Section aims to offer an overview of the essential elements required to address the two research questions.

As reported in [Table 2](#), the majority of the corpus aims to summarise and describe the features of the phenomenon (*descriptive analysis*) (47.2%). This observation suggests that HSC resilience research is currently in a transition period between the nascent and intermediate states.

Six theoretical lenses emerged from the analysis. These were used by only 8.6% of the corpus, indicating limited adoption of explicit theoretical lenses. In particular, the complex adaptive system (CAS) theory has been increasingly employed to explain supply chain resilience in volatile, uncertain and complex environments ([Aigbogun, 2023](#)). Furthermore, it supports the selection of S–E perspective for the analysis of the resilience of the HSC, as a S–E system can be regarded as a particular instance of CAS ([Wieland and Durach, 2021](#)).

The analysis of disturbances in the corpus reveals key research priorities and interests in the scientific community. Most studies focus on low-frequency-high-impact disturbances (68.5%), whereas 18.0% examine high-frequency-low-impact events – primarily equipment breakdown – and 13.5% address both. However, resilience is still primarily framed from an engineering rather than a S–E perspective.

5. Elements of HSC resilience principles

As evidenced by the descriptive analysis, only one paper in the corpus explicitly employs the theoretical framework of S–E resilience. Consequently, there is an absence of explicit reference to the principles of S–E resilience ([Biggs et al., 2012](#); [Wieland et al., 2023](#)). However, some elements of these principles can be intuitively discerned in the HSC resilience literature (answering [RQ1](#)). See [Appendix A1](#) for definitions.

Recognising that there is a limit to what any single organisation can achieve without support from other stakeholders ([Vanvactor, 2011](#)), one of the most important elements referenced in the corpus is *collaboration*, defined in the HSC as the ability of hospitals, suppliers, manufacturers and government entities to work together effectively to anticipate, withstand and recover from

Table 2. Descriptive characteristics of the reviewed articles ($n = 89$)

		No. of articles
Publication outlets *	Journals	80
	Conference Proceedings	4
	Book series	5
Publication year	2014-2016	3
	2017-2019	10
	2020-2022	46
	2023-2025	30
		% of the corpus
Research aim**	Descriptive	47.2
	Exploratory	22.5
	Explanatory	30.3
Research method**	Case studies	25.2
	Interviews	19.3
	Optimisation	14.8
	Survey	13.3
	Multi-criteria decision-making	11.9
	Data analysis	5.9
	Simulation	5.9
	Focus group	1.5
	Delphi	1.5
Theoretical lens**	Spatial analysis	0.7
	Complex adaptive systems	2.2
	Dynamic capability	2.2
	Organisational information processing	2.2
	Resource-based view	2.2
	Resilience theory	1.1
	Supply chain resilience theory	1.1
SC resilience perspective	Engineering	69.7
	Ecological	29.2
	Social-ecological	1.1
Unit-of-analysis	Networks	56.2
	Triad	18.0
	Dyads	6.7
Disturbance**	Single organisation	19.1
	Low-frequency high-impact	
	Pandemic	60.7
	Natural disaster	32.6
	Man-made disaster	29.2
	High-frequency low-impact	
	Equipment breakdown	11.2
	Demand fluctuation	9.0
	Material shortage	7.9
	Delay	5.6
	Error	5.6
	Regulatory constraint	3.4
	Strikes	3.4
Counterfeit	2.2	
Supplier failure	2.2	
Other	2.2	

Note(s): * Details of the corpus source title are available as supplementary materials S1

** Articles may fall into more than one category

disturbances (Aigbogun, 2023; Ganguly and Farr, 2023). This element (mentioned in about 34.8% of the corpus) is a component of the *broaden participation* and *manage connectivity* principles. *Manage connectivity* is also supported by two other elements: *agility* – defined within the HSC as the ability to react quickly and competently to disturbances and patient requirements (Shweta et al., 2022) and mentioned in about 21.3% of the corpus – and *visibility* – defined as the extent to which actors within a supply chain have access to or share information which they consider key or useful to their operations (Ganguly and Farr, 2023) and mentioned in about 21.3% of the corpus. Another important resilience element is *flexibility* (mentioned in about 28.1% of the corpus), defined as the ability to adapt to both positive and negative impacts within the HSC by reconfiguring operations under variable conditions (Bø et al., 2023; Shweta et al., 2022). This element is a component of the *foster CAS thinking principle*. The *manage slow variables and feedbacks* principle is at the root of three other elements: *agility*, *visibility* and *flexibility*. Two relevant resilience elements of *maintain diversity and redundancy* principle can be found in HSC resilience literature. These are *redundancy* and *robustness*. The former (mentioned in about 9.0% of the corpus) is defined as the strategic incorporation of surplus capacity or resources to mitigate disturbance impacts (Zamiela et al., 2022) whereas the latter refers to the capability of the supply chain network to accommodate and deal with unexpected events endure disturbance risks (Hasani, 2021) (mentioned in about 10.1% of the corpus). Redundancy is also an element of the *broaden participation* principle.

These elements, and therefore the S–E resilience principles, are also linked to the resilience capabilities. Persistence capability is strongly linked with *maintaining diversity and redundancy*. This principle fosters persistence by acting proactively in the face of potential disturbances (Shweta et al., 2022). In the aftermath of a disturbance, *foster CAS thinking* and *manage slow variables and feedback* assume paramount importance in facilitating adaptation. These principles enable HSC to sense threats, react and adapt to changing requirements with minimal time, effort, cost and performance drop (Lima et al., 2018). Similarly, *broaden participation* is essential for ensuring resilience as a transformation capability, generating competitive advantages, reducing uncertainty, and improving the level of integration between SC entities (Araujo et al., 2022). Some examples taken from the paper corpus are reported in Table 3. S–E resilience principles can be used to help HSC progress on the adaptive cycle and can be used as a lever to reduce the factors (such as barriers) hindering the progression toward a more desirable HSC state.

We did not identify in the corpus any element components of the *encourage learning* and *promote polycentric governance* principles. Regarding learning, Dagenais et al. (2023) present the lessons learned from the changes observed during the pandemic in different countries. In contrast, Sawyerr and Harrison (2022) stated that there was not much evidence for lessons learnt after the pandemic. This suggests that learning in the HSC is uneven and context-dependent. In particular, the lack of elements linked to encouraging learning may be due to the fact that some of the lessons learned cannot be applied directly by HSC actors, as they fall under the responsibility of other levels (e.g. government policy) (Dagenais et al., 2023). This misalignment may prevent learning from being activated or formalised at the supply chain level, limiting its traceability in empirical contributions. Furthermore, the governance structure of the sector, which is largely centralised, constrains the autonomy of individual HSC actors and limits their ability to apply lessons learned independently, reinforcing the challenge of translating learning into practice. Regarding polycentric governance, the centralised nature of decision-making within the HSC contrasts with the decentralised governance structures, which can enable more adaptive and localised responses. For instance, Dagenais et al. (2023) report that the integration of health and social services facilities into decisional centres reinforces their lack of autonomy to plan their stocks to anticipate resource scarcity. Within the healthcare system context, the realisation of decentralised governance is inherently challenging. All actors, products and services must meet rigorous quality and safety requirements. A centralised approach ensures compliance with these requirements (Aigbogun, 2023; Mandal, 2017).

Table 3. HSC social-ecological resilience principle in relation to resilience capabilities

Social-ecological resilience principles	Resilience capabilities		
	Persistence	Adaptation	Transformation
Maintain diversity and redundancy	Maintaining diversity and redundancy in HSC ensures continuous operations by mitigating disturbances. For example, building redundant inventory helps sustain HSC functionality during unexpected events (Ganguly and Kumar, 2019). Additional capacity enhances immediate responsiveness to uncertainties (Shweta <i>et al.</i> , 2022)	Redundancy actions, like multiple sourcing, can provide greater flexibility when adapting to disruptions (Ash <i>et al.</i> , 2023). Redundancy can provide extra time to think about effective solutions (Shweta <i>et al.</i> , 2022)	
Foster CAS thinking		Fostering CAS thinking enhances the ability to navigate uncertainties through flexible responses. This ensures that the consequences of unexpected events can be effectively managed (Salehi <i>et al.</i> , 2020). In HSC, flexibility allows adaptation to changing demands without incurring excessive costs or performance losses (K.E.K. <i>et al.</i> , 2022)	In turbulent contexts, the ability to sense the need to reconfigure an organisation's asset structure and to carry out the necessary internal and external transformation is valuable (Xiao and Khan, 2024). HSC should focus on using this turbulence to their advantage rather than being adversely affected due to changes (Rehman and Ali, 2021)
Manage slow variables and feedback	A quick recovery to the pre-disturbance state is possible if SC managers enhance visibility among all elements of the supply chain by implementing data-sharing policies and utilising the latest technologies (Shweta <i>et al.</i> , 2022). Rapid sharing of critical information regarding potential dangers is necessary to prevent the supply chain from breaking down (Xiao and Khan, 2024)	Managing slow variables and feedback enables adjustments to maintain system stability during disturbances. Real-time visibility of disturbances enables the maintenance of situational awareness of disturbances in supply chains and their potential effects in real-time (Hallikas <i>et al.</i> , 2023). Continuous adjustment based on feedback ensures that routines and procedures remain up-to-date (Bø <i>et al.</i> , 2023)	The resilient supply chain develops the capability for continuous improvement by analysing the company's strengths and weaknesses, as well as opportunities and threats (Shweta <i>et al.</i> , 2022). Knowledge management and disruptive environment awareness can create a resilience-seeking culture promoting transformation (Sawyer and Harrison, 2022)

(continued)

Table 3. Continued

Social-ecological resilience principles	Resilience capabilities Persistence	Adaptation	Transformation
Broaden participation, Manage connectivity		Collaborative resilience enhances the adaptability potential of HSCs to address systematic disruptions and spill-over effects, regardless of the source or geographical location of a medical stockout, the time of occurrence, or the point of impact (Friday et al., 2021)	Broadening participation strengthens system resilience by fostering inclusive decision-making and resource sharing. In HSC, strong supplier collaboration plays a critical role by enabling the exchange of essential information, infrastructure, and technologies among stakeholders. This interconnected approach ensures that no healthcare organisation operates in isolation during crises (Furstenau et al., 2022). For instance, a form of improved status quo is achieved when the network is expanded to include suppliers and maintain a dialogue between buyers and suppliers (Beaulieu et al., 2024)

In summary, the analysis presented in Section 5, which answers RQ1, highlights how the elements intuitively discerned in the HSC resilience literature can be traced back to the principles of socio-ecological resilience and are consistently linked to the related resilience capabilities. This demonstrates that socio-ecological resilience is an applicable and useful approach for the HSC context, as it provides a solid theoretical framework for interpreting the sector’s ability to persist, adapt and transform in the face of disruptions. Consequently, the following section will explain the context-specific insights that enable the achievement of HSC socio-ecological resilience.

6. Characterising the social-ecological healthcare resilience

In this section, the actions that influence HSC resilience are analysed using the S–E perspective, enriching the theoretical framework presented in the Background section, thereby answering RQ2. The resilience actions referenced in the corpus are most often implemented before a disturbance (48.1%), whereas 32.1% are implemented both pre- and post-disturbance. The remaining 19.8% focused on resilience in the post-disturbance phase (Figure 3) (see Appendix A2 for definitions). The following sections will describe how these actions affect the three resilience capabilities.

6.1 HSC persistence

6.1.1 Pre-disturbance resilience actions. Pre-disturbance actions focus on the time frame preceding a disturbance to the HSC (Götz et al., 2024) and aim to increase its persistence. Pre-disturbance actions imply that the supply chain implements ex-ante measures to cope with disturbances, with no adaptation needed during times of change (Vann Yaroson et al., 2021).

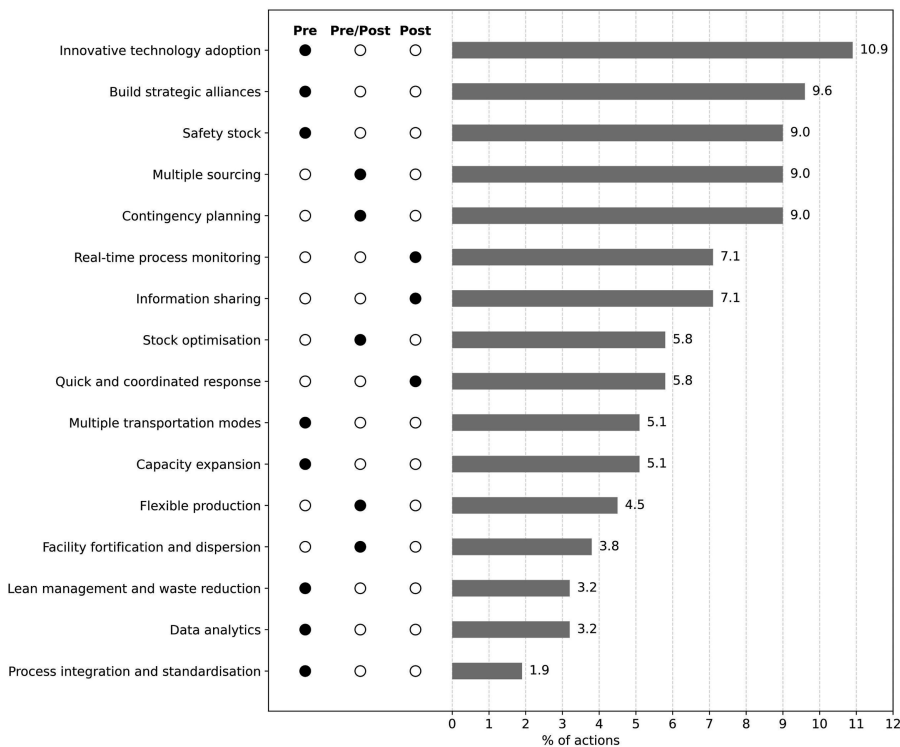


Figure 3. HSC resilience actions (100% refers to all actions cited, not the number of papers)

In other words, actions taken in preparation for future disturbances are expected to enable “operations as normal”, i.e. operational continuity (Ganguly and Kumar, 2019).

Indeed, most of the supply chain actions highlighted in the analysed corpus are implemented before a disturbance (Ganguly and Kumar, 2019); some examples are stockpiling medical devices, equipment and products (Ash *et al.*, 2023; Vanvactor, 2011), implementing multiple sourcing (Rehman and Ali, 2021), developing a warning system based on technologies (Furstenau *et al.*, 2022) and reinforcing the facilities (Hasani and Khosrojerdi, 2016). Some of these actions require a long implementation period, such as facility reinforcement or process standardisation (Bruckler *et al.*, 2024). If these pre-disturbance actions successfully contrast a disturbance upon its occurrence, the HSC maintains the status quo and operational continuity through persistence.

Nevertheless, actions implemented in anticipation of a future disturbance cannot guarantee effectiveness, as these actions may prove inadequate in averting the adverse consequences of actual disturbances. The reasons for this are manifold within the HSC. First, managers are reluctant to justify enough investments in actions to mitigate disruptive events that have a low probability of occurrence (Ganguly and Kumar, 2019). High pre-disturbance investments are hardly compatible with healthcare organisations’ historical pursuit of the lowest purchase price (Beaulieu *et al.*, 2024). This results in implementations of actions that are not structured or pervasive enough to handle high-impact disturbances effectively. Moreover, given the scale, scope and complexity of today’s HSCs, it is infeasible for HSC managers to anticipate and prepare for every potential risk. As supply chains inevitably become more global, their vulnerability also increases (Aigbogun, 2023). Even in cases where contingency plans are established, they typically remain dormant for extended periods, potentially becoming irrelevant when disturbances of low predictability and high impact occur (Bø *et al.*, 2023). The case of pandemic preparedness plans exemplifies this: these plans were present but not updated in several countries, and they proved to be inadequate during the COVID-19 pandemic, thereby requiring the implementation of additional post-disturbance actions to maintain operational continuity (Butler, 2024; Giuffrida and Boseley, 2020; Mnyanda, 2023).

6.1.2 Post-disturbance resilience actions. After a disturbance hits, if pre-disturbance actions are insufficient to maintain operational continuity, the HSC is compelled to implement additional post-disturbance actions (Ward and Hargaden, 2019; Vann Yaroson *et al.*, 2021; Zaza *et al.*, 2022). Some examples of post-disturbance resilience actions are lateral transshipment, i.e. hospitals that have major availability of drugs try to compensate for the shortcomings in other hospitals (Aldrighetti *et al.*, 2019), backup suppliers and/or flexible distribution systems (Vann Yaroson *et al.*, 2023b) and establishing a response team (Vanany *et al.*, 2022). The quicker the HSC reacts to the disturbance, the faster it will return to its normal state; conversely, the HSC may encounter the risk of being unable to guarantee operational continuity (Vanany *et al.*, 2022).

Post-disturbance actions aim to respond as quickly as possible by implementing a predefined set of responses (Tortorella *et al.*, 2022). The term “predefined” here refers to the fact that these actions are already known to the decision-makers, in contrast to “emergent” actions, which are context-specific to the disturbance and unknown *a priori*, as discussed later in Section 6.2. Implementing effective predefined post-disturbance actions facilitates a return to the pre-disturbance status quo. It can thus be stipulated that such predefined post-disturbance actions increase the resilience of the HSC in terms of persistence, in a manner similar to pre-disturbance actions. Furthermore, pre-disturbance actions can enhance post-disturbance ones (Vann Yaroson *et al.*, 2023b). For instance, strategic alliances built in preparation for future disturbances can support joint decision-making during disturbances (Vann Yaroson *et al.*, 2021).

6.2 HSC adaptation

Predefined post-disturbance actions are sometimes ineffective due to an underestimation of the disturbance impact (Aigbogun, 2023), the selection of inappropriate actions

(Doroudi *et al.*, 2018), or the absence of effective and feasible predefined actions to counteract the specific effects of the ongoing disturbance. For these reasons, after a disturbance, HSCs explore, design and implement additional measures to enhance resilience and mitigate the disturbance's ongoing effects. If the measures are small and incremental, the system develops *adaptation* capabilities (Wieland *et al.*, 2023), while more radical changes are associated with *transformation* (as described in Section 6.3). Adaptive actions differ from the aforementioned persistence actions, which are designed to overcome disturbances by remaining rigid and not adapting. This may be particularly true in the case of low-frequency-high-impact disturbances, where predefined actions often fail to account for the unique characteristics of the disturbance and the adverse effects it generates. In other words, to develop adaptation capability, HSCs must implement *emergent* post-disturbance resilience actions. These actions should not be viewed as part of a predefined set, but rather as context-specific, relatively small adjustments to the disturbance and the changes it causes (Aigbogun, 2023). Indeed, during low-frequency-high-impact disturbances, decisions must be made quickly and based on incomplete and contextual information (Furstenau *et al.*, 2022). In this case, the HSC must adjust and modify its normal functioning in ways that cannot be predetermined.

The implementation of emergent post-disturbance actions leads to a *new post-disturbance state*, through incremental changes that allow the HSC to better serve the new needs that emerge after the disturbance. Therefore, this transition is determined by the HSC's ability to reorganise itself and modify its functioning to better respond to the ongoing disturbance, thus building adaptation capability. This adaptive capability is evidenced by the creation of new services in response to changing community needs (Jamal *et al.*, 2020). For example, pre-crisis contingency plans, such as those ensuring medicine supply during shortages, require revisions due to the unexpected scale of the emergency (Jamal *et al.*, 2020). Another example is the expansion of HSC capacity to supply the social care sector with personal protective equipment at the height of the pandemic (Scala and Lindsay, 2021).

However, supply chains, and HSC in particular, have long neglected the dynamic nature of supply chains and the need to constantly adapt and evolve in response to disturbances (Ward and Hargaden, 2019). In fact, even after the reorganisation phase has been reached, it is common for the HSC to revert to its previous status quo of conservation, abandoning the changes implemented in response to disturbance. For example, to address the shortage of health personnel in the first COVID-19 wave, hospitals recruited short-term contractors and organised rapid training for candidates. However, at the end of the first wave, managers dismissed many of these contractors. The sharp increase in the number of COVID-19 patients during the second wave necessitated the recall of those workers, but most refused to return (Dagenais *et al.*, 2023). During shortages, HSC actors modified their standard procedures by adopting alternative forms of treatment, adjusting dosage, volume, or formulation, to ensure the continuity of care (Vann Yaroson *et al.*, 2021). This operational shift reflects an adaptive response, whereby the HSC altered its functioning to meet emergent patient needs, rather than maintaining pre-disturbance norms. Moreover, during the Syrian war, shelters were established in hard-to-reach areas, and emergency health teams were deployed to areas of active conflict (Jamal *et al.*, 2020). However, once the disturbance subsided, these practices were discontinued. When such actions are withdrawn and the HSC reverts to pre-disturbance practice, this reflects persistence rather than adaptation, indicating that the actions were context-specific and not integrated into long-term operations (Vann Yaroson *et al.*, 2021). This phenomenon can be interpreted as a "bounce back" to the prevailing status quo. In other words, the achievement of a more desirable post-disturbance state is not sustained. Consequently, the concept of adaptive capability entails the HSC's capacity to modify its functioning in response to disturbances and, in some cases, consolidate incremental yet enduring changes that enhance S-E resilience. When changes are abandoned instead, this is more reflective of persistence rather than true adaptation.

6.3 HSC transformation

In certain cases, transformative resilience is achieved, involving a radical departure from the existing system in response to a disturbance. Transformative actions permanently modify the system or processes to better cope with the post-disturbance environment. There are documented cases of success. For example, at Rady Children's Hospital in San Diego, designers created an intensive care unit with a 60-bed floor plan that can be converted into 20 fully isolated rooms for infectious disease patients (Kamin, 2022). New healthcare services were permanently introduced in Syria to mitigate the war's negative consequences to patients and the staff. These actions led to radical changes, in which disturbance serves as an opportunity for improvement and innovation, enabling the HSC to implement new procedures or services and thus evolve by adapting to the new post-disturbance environment. As HSCs respond to disturbances, they gain valuable experience that can inform their pre-disturbance actions (Harland *et al.*, 2021). Therefore, post-disturbance actions (emergent or predefined) could become part of the pre-disturbance actions implemented by HSC to prepare for future disturbance in a new adaptive cycle. Examples of transformative resilience are limited, primarily because most papers adopt an engineering resilience perspective. Moreover, transformative actions are characterised by increased complexity in implementation, greater effort requirements and barriers that impede execution.

6.4 HSC adaptation and transformation hindering factors

Barriers, often specific to certain industries, can hinder S–E resilience in the HSC, inhibiting persistence, adaptation and transformation. Only 19.0% of the corpus addresses these barriers (with each paper discussing one or more). Table 4 outlines the key barriers that affect HSC resilience (see also Appendix A3). In this section, barriers are presented in relation to adaptation and transformation capabilities, as these capabilities are connected to achieving the new post-disturbance state, enabling the exploitation of disturbances as an opportunity for improvement.

For instance, in the pharmaceutical industry, the structural and regulatory complexity of the supply chain, characterised by stringent regulations, long lead times and a limited number of suppliers, can reduce the effectiveness of certain resilience actions (Vann Yaroson *et al.*, 2023b). Similarly, in public HSCs, a growing focus on efficiency, cost minimisation, inventory reduction

Table 4. HSC resilience barriers (100% refers to all barriers cited, not the number of papers)

HSC resilience barriers	Effect on HSC resilience	Frequency
Lack of resources	The lack of resources is particularly pertinent in the context of public health systems that are constrained by budgetary limitations	23.9%
Uncertainty	Rising volatility and uncertainty in global supply chains constitute a barrier to resilience. The healthcare sector's inherent uncertainty is related to difficulties in predicting medical, blood and pharmaceutical supply and consumption, as well as policy changes	23.9%
Structural and regulatory complexity	Multiple stakeholders, strict production, distribution deadlines, and volatile demand contribute to HSC complexity. Complexity complicates the design and execution of resilience actions	19.3%
Lack of data	The lack of or poor quality of data might reduce the overall efficiency of the supply chain and, consequently, constitute a barrier to its resilience	14.8%
Fragmentation	The health sector, particularly the hospital sector, is highly compartmentalised. There is a lack of cohesion and consultation among stakeholders, which constitutes a barrier to the effective implementation of resilience actions	10.2%
Globalisation	Business organisations are going global and increased interconnectivity between various industries and organisations has made supply chains even more vulnerable to any disaster occurring in any part of the world	8.0%

and maximisation of utilisation across the entire supply chain (due to limited resources) can undermine the long-term benefits of resilience actions (Götz *et al.*, 2024). For example, maintaining a low inventory to pursue cost-efficiency in the public healthcare system prevents it from responding to sudden increases in demand (Götz *et al.*, 2024). As another example, in publicly funded healthcare systems, budget constraints (a lack of resources) may limit the implementation of resilience actions, such as investing in advanced forecasting tools, which are deemed too costly despite their potential to mitigate severe disturbances (Thomson *et al.*, 2022). Due to public health budgetary austerity, several countries have closed or merged public health bodies and reduced spending on public health, including preparedness for pandemics (Thomson *et al.*, 2022). Additionally, the presence of numerous stakeholders (fragmentation) with contrasting objectives may determine healthcare-specific barriers (Friday *et al.*, 2021). During the COVID-19 pandemic, the fragmented application of existing risk management capabilities hindered efforts to enhance resilience against medical stockouts (Friday *et al.*, 2021). These examples illustrate that, while HSC may implement emergent, adaptive and transformative post-disturbance actions to cope with disturbances, structural, regulatory and resource constraints can hinder the permanent adoption of these actions and the progression toward a new, better post-disturbance state, thereby reversing the HSC to its previous status quo. These make it impossible to exploit disturbances as opportunities for improvement.

7. Discussion and future research avenues

Our study demonstrates that the theoretical lens of S–E resilience (Wieland and Durach, 2021) is not only applicable in the context of HSC, characterised by high dynamism and variability, but is also advantageous because it offers a theoretical framework for interpreting the relationship between the actions, barriers and principles influencing resilience and resilience capabilities. This lens has broadened the discourse on HSC by focusing on the evolution towards a better status quo, more suited to survival in the post-disturbance environment, which was previously little considered in the literature. Using this theoretical lens allows us to assess the evolution of HSC over time, evaluating how to manage and facilitate transitions from one phase to the next of the adaptive cycle by enabling resilience capabilities, thus overcoming the previous rigid classification of actions into simple pre- and post-disturbance categories, and directly relating actions to the respective enabled capabilities. In addressing RQ1, the principles of S–E resilience have been associated with the capabilities they enable (see Table 3), thereby broadening the interpretation of S–E resilience provided in the literature to date. This analysis highlights promising areas for future research, particularly those that investigate the previously unexplored relationship between principles and capabilities. Applying the S–E resilience lens to HSC has enabled a better characterisation of the barriers that limit transformation and adaptation (RQ2), thereby hindering progress towards a better status quo and continuous improvement. The previous engineering perspective focused solely on responding to the acute phase of disturbances, without considering how to leverage disturbances as opportunities for improvement. S–E resilience allowed us to highlight this gap and propose an initial identification of these barriers. This extends the theoretical lens of socio-ecological resilience, highlighting that if barriers are not addressed, progression along the adaptive cycle can be blocked. Vice versa, our study showed that contextualising S–E resilience is instrumental to operationalising these barriers. Theorising HSC as a socio-ecological system enables us to explain the discrepancies and conflicting opinions identified in the literature, thereby clarifying its resilience. For example, this approach can help overcome the fragmented definitions of HSC resilience found in the literature (Araujo *et al.*, 2022), which range from an emphasis on rapid response to disturbances (Bastani *et al.*, 2021) to a focus on long-term growth (Scala and Lindsay, 2021). Furthermore, discrepancies are evident in how HSC resilience is measured, as there is currently no consistent, universally accepted method (Goodarzi *et al.*, 2022; Scala and Lindsay, 2021).

The literature review results were formalised in the theoretical framework presented in Figure 4.

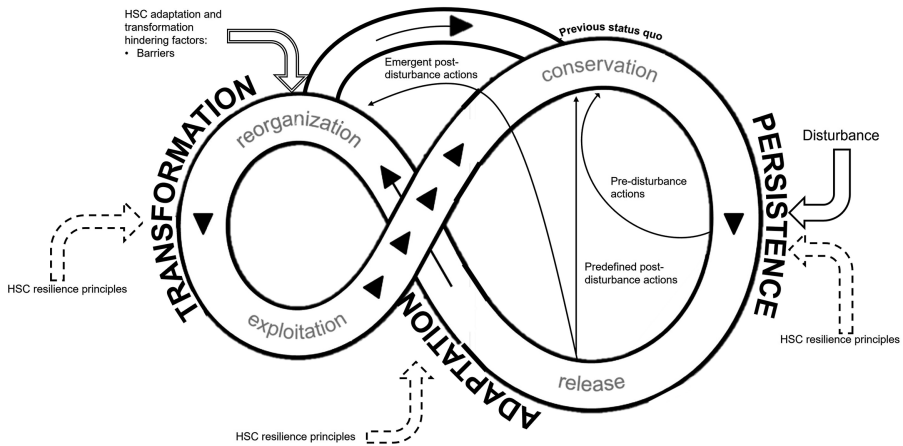


Figure 4. Refined HSC social-ecological resilience framework resulting from the CLR. Dashed lines represent principles; double lines represent barriers. Adapted from [Holling \(1986\)](#) and [Wieland and Durach \(2021\)](#)

The framework describes the evolution of an HSC facing disturbances. Before a disturbance, the HSC can apply pre-disturbance actions as a mitigation lever promoting persistence. When a disturbance occurs, predefined post-disturbance actions are implemented to restore the previous status quo. In contrast, unexpected impacts require emergent post-disturbance actions, potentially leading to adaptation and transformation towards a new post-disturbance state. Adaptation and transformation-hindering factors can impede the transition to exploitation, returning the HSC to the previous status quo. Overcoming these hindering factors enables entry into the exploitation phase, thereby completing the transformation to a new, resilient state. Developing persistence, adaptation and transformation capabilities requires applying resilience principles progressively.

Furthermore, this perspective opens several avenues for future research, as detailed below. The first research avenue entails considering the HSC as a socio-ecological system, as we proposed here with our reframing of the existing literature. Following our example, researchers could apply the S–E system theory lens ([Wieland and Durach, 2021](#)) to study the HSC not as a static system, but as a continually evolving one, thus requiring it to be observed at different points in time to grasp its true nature. The same approach can also be used in other sectors. Taking the S–E system theory as a theoretical lens, the second research avenue proposes studying how different resilience actions can enable S–E resilience. Our study proposes that in the context of HSC, resilience research should distinguish between three types of actions: pre-disturbance, predefined post-disturbance and emergent post-disturbance. Each type can foster distinct resilience capabilities, and future research should investigate which specific actions activate this effect and how this mechanism unfolds. Overcoming the previous categorisation into proactive and reactive strategies ([Ganguly and Kumar, 2019](#); [Vann Yaroson et al., 2023b](#)), these future research avenues can leverage SC resilience theory and the resource-based view to identify and characterise the actions that build persistence capability. Instead, dynamic capabilities would be a suitable theoretical framework for actions that support adaptation capability.

Our literature review highlighted that certain barriers to HSC resilience have been identified in previous studies. Nevertheless, we introduced a novel conceptualisation of these barriers as hindrances to the adaptation and transformation of the supply chain. In addition, barriers might be only one of the factors hindering the HSC transition towards a more resilient status. Therefore, the third research avenue focuses on identifying the factors hindering HSC adaptation and transformation, particularly the lack of formalisation of lessons learned and the explanation of underlying mechanisms. The SC resilience theory can effectively serve this exploration.

Finally, the last future research avenue builds on our novel conceptualisation of the HSC resilience capabilities as cumulative; thus, future research should embrace this cumulative nature to understand how and under which conditions it is possible to reach full resilience. The cumulative capabilities concept, dynamic capabilities and contingency theories can help frame this future research avenue. Furthermore, future research may investigate the still-unexplored relationships between resilience principles and capabilities.

8. Conclusions

This research has validated the applicability of the S–E resilience framework to the HSC context. S–E resilience principles were contextualised for the HSC context (RQ1), demonstrating that the S–E resilience theory is applicable and useful for studying resilience in HSC. Contextualising the theory helped identify additional elements that had not been theorised before and operationalise them, thanks to a narrower approach. From this perspective, this study identified actions that promote and barriers to the development of persistence, adaptation and transformation capabilities (RQ2). Reading the literature on HSC through this lens enables us to understand how to help HSC progress towards a better post-disturbance state, broadening the discourse on HSC resilience. Therefore, this study offers a conceptual foundation for analysing HSC resilience through an S–E lens, and lays the groundwork for future studies that aim to empirically validate these categories and refine the conceptual model.

HSC managers should shift their focus from maintaining short-term operational continuity to actively integrating adaptation and transformation into resilience actions. This approach ensures that the HSC not only survives disruptions but also evolves into a better state. To achieve this, managers need to identify and overcome sector-specific barriers that lead to a predominant focus on engineering resilience, thereby overlooking opportunities to turn disturbances into opportunities for improvement. Employing a S–E perspective, both before and after disruptions, can help managers determine which resilience capabilities are underdeveloped and need targeted actions.

The study's findings demonstrate that fostering S–E resilience in HSCs directly benefits patients, healthcare professionals and the broader community. Investing in adaptive and transformative resilience in HSCs is essential because it promotes an evolution towards better and more equitable conditions. HSCs with this capacity not only ensure continuity of care and rapid responses to the population's needs during disturbances but also reduce inequalities and strengthen patient confidence through structural and innovative changes. Communities benefit from more equitable access to care, while healthcare professionals can rely on improved resources and procedures to manage and work effectively during disruptions. The lack of this form of resilience can lead to delayed responses, the maintenance of existing inequalities and a loss of confidence, thus compromising the quality and equity of healthcare.

This paper has some limitations. The search query excludes all studies that discuss components of the resilience concept (e.g. response, recovery, preparedness). Moreover, an additional limitation pertains to the HSC under consideration. The present study draws on insights into the HSC in its broader sense, with particular emphasis on care delivery. This may have led to the exclusion of papers that referenced specific sub-components, such as the blood supply chain, pharmaceuticals and hospitals. Ultimately, the query contains terms related to actions, barriers and principles. It is essential to note that alternative keywords for these terms may not be included in the search string. All these search limitations need to be addressed in future research. Furthermore, differences in governance and reimbursement models across countries have not been considered at this stage, as the analysis was primarily concerned with physical flows. Including government agencies, policymakers and insurance companies in the analyses could enhance the understanding of the whole healthcare ecosystem and facilitate the identification of additional actions, principles and barriers.

Table A1. HSC resilience principles and elements

HSC resilience principles elements	Frequency (% of papers citing the action, each paper can cite more than one)	Definition	HSC resilience principles	Example
Collaboration	34.8%	Ability of hospitals, suppliers, manufacturers and government entities to work together effectively to anticipate, withstand and recover from disruptions. This collaborative approach is essential for ensuring the timely and consistent delivery of critical medical supplies and services	Broaden participation	Collaboration refers to the level of teamwork within a supply chain. It represents the ability to integrate cooperative partners into a unified system and to frame collaborative planning through coordinated information and knowledge sharing at the individual level, enabling quick recovery actions during disruptions (Shweta et al., 2022). Collaboration refers to the interaction among supply chain members working together to create a competitive advantage through information sharing, joint decision-making and benefit sharing (Araujo et al., 2022)
			Manage connectivity	Collaboration translates into supply chain integration, as well as the commitment of internal resources and suppliers. When relationships are based on mutual trust and joint planning, supply chain actors create the proximity necessary to find business continuity solutions (Araujo et al., 2022). Effective collaboration further enables the leveraging of knowledge from customers and suppliers, while streamlining information and product flows, thereby enhancing supply chain resilience (Ganguly and Farr, 2023)
Flexibility	28.1%	Ability to adapt to both positive and negative impacts within the HSC by reconfiguring operations under variable conditions	Foster CAS thinking	Flexibility reflects a CAS perspective, as it entails multiple organisational networks adapting to internal and external changes (Xiao and Khan, 2024). Flexibility forms a direct response to changes in the existing situation (Bø et al., 2023)
			Manage slow variables and feedbacks	Flexibility entails the ability to sense threats, react and adapt to changing requirements with minimal time, effort, cost and performance loss (Lima et al., 2018)

(continued)

Table A1. Continued

HSC resilience principles elements	Frequency (% of papers citing the action, each paper can cite more than one)	Definition	HSC resilience principles	Example
Agility	21.3%	Ability to respond quickly with competence and speed of reaction to interruptions and patients' requirements. A responsive and agile approach allows immediate reaction to uncertain events	Manage slow variables and feedbacks	Agility is achieved by monitoring every node of the SC in real time, which facilitates quick decision-making (K.E.K. <i>et al.</i> , 2022). Real-time monitoring of disruptions also maintains situational awareness across the supply chain (Hallikas <i>et al.</i> , 2023). The level of agility depends on the degree of transparency, enabling supply chains to compete under continuous change and implement innovative solutions (Jafarnejad <i>et al.</i> , 2019; Zamiela <i>et al.</i> , 2022)
			Manage connectivity	Agility is determined by several factors, including the integration of the purchasing team, monitoring results and relationships with customers and suppliers. Agile companies typically have a small supplier base, prioritise strong relationships and share information to enhance the level of purchasing connectivity (Araujo <i>et al.</i> , 2022)
Visibility	21.3%	Possibility of having access and sharing key information within the entire supply chain. High visibility enables the quick detection of signals and the monitoring of the entire supply chain	Manage slow variables and feedbacks	Visibility within a supply chain enables an organisation to have a clear understanding of the entire supply chain, thereby helping to detect signals of future disruptions (Ganguly and Kumar, 2019). Enhancing visibility also improves awareness of vulnerabilities, allowing supply chains to better understand each node (Scala and Lindsay, 2021)
			Manage connectivity	Visibility supports managers in decision-making, relying on effective information systems and strong connectivity across the entire network (Lima <i>et al.</i> , 2018)
Robustness	10.1%	Ability to withstand adverse conditions. Robustness fosters supply resilience by acting proactively during potential disruptions	Maintain diversity and redundancy	Robustness enables the supply chain to rapidly activate the resources and capabilities prepared by the preparedness and anticipation capabilities to mitigate and limit the impact of unavoidable disruptions (Sawyer and Harrison, 2022). Multiple-sourcing models, which allow several depots to serve customers, are excellent for designing an effective and robust supply network (Sazvar <i>et al.</i> , 2021)

(continued)

Table A1. Continued

HSC resilience principles elements	Frequency (% of papers citing the action, each paper can cite more than one)	Definition	HSC resilience principles	Example
Redundancy	9.0%	Ability to strategically incorporate surplus capacity or resources into the HSC to mitigate the impact of disruptions. The key lies in finding the right balance between efficiency and redundancy	Maintain diversity and redundancy Broaden participation	Redundancy refers to the generation or maintenance of duplicate resources and services. The additional capacity can be created for manufacturers, suppliers, transporters, inventory and warehousing, so that it can be utilised immediately during unexpected and uncertain disruptions (Shweta et al., 2022) Redundancy can additionally be established through comprehensive contingency planning, which facilitates emergency sourcing and the strategic diversification of suppliers and transportation partners (Shweta et al., 2022)

Table A2. Healthcare supply chain resilience actions

HSC resilience actions	Definition	Implementation phase	Frequency (% of papers citing the action, each paper can cite more than one)	Coded themes examples
Innovative technology adoption	Adoption of a variety of technologies (e.g. blockchain, smart contracts, automated guided vehicles and artificial intelligence) to improve the proactive and reactive resilience capabilities of HSCs	Pre-disturbance	19.1%	“Digitalization is one of the methods how the resilience of the SC can be improved. The adoption of a Supply Chain 4.0 [. . .] may enhance the level of the SC’s processes maturity, collaborating for the achievement of higher resilience” (K.E.K. <i>et al.</i> , 2022)
Build strategic alliances	Relationship between two or more firms in the HSC, based on the agreed degree of integration and underlying contractual agreements. Strategic alliances are suggested to enhance HSC resilience, as they increase trust and facilitate information sharing	Pre-disturbance	16.9%	“Strategic alliances with their upstream SC partners ensured continuity and enabled them to plan for a disruption” (Vann Yaroson <i>et al.</i> , 2023a)
Safety stock	Store critical materials, drugs, consumables and equipment in preparation for disruptions	Pre-disturbance	15.7%	“Extra inventory that is designed to be used to meet customer demand in the event of a supply chain disruption” (Lücker <i>et al.</i> , 2019)
Contingency planning	Development of plans that are meant to help healthcare organisations respond effectively to disturbances that may or may not occur in the future	Pre and post-disturbance	15.7%	“The contingency plan is designed in parallel to the usual plan of an organization. This plan comes into action when there is an instant need. Hence, it is not a full-time operational plan. It acts like a backup strategy to tackle risk and disruptions” (Shweta <i>et al.</i> , 2022)

(continued)

Table A2. Continued

HSC resilience actions	Definition	Implementation phase	Frequency (% of papers citing the action, each paper can cite more than one)	Coded themes examples
Multiple sourcing	Sourcing each product from multiple primary suppliers, more effective than single sourcing at mitigating the risks of high operating costs and low service levels	Pre and post-disturbance	15.7%	“Employed the multiple sourcing and assignment strategy (e.g. using multiple suppliers for providing raw materials, or allocating a customer to multiple distribution centers) to improve the resiliency of the logistics system” (Nayeri <i>et al.</i> , 2022)
Information sharing	Timely exchange of relevant data and insights among parties, which is essential for building resilience. Without this flow of information, opportunism may arise, demand signals become distorted and partners can experience dissatisfaction due to inadequate capacities for responding effectively to changes or challenges	Post-disturbance	12.4%	“Proper information sharing along the supply chain greatly aids in increasing information visibility and leads to an increase in its resiliency” (Ganguly and Farr, 2023)
Real-time monitoring	HSCs’ capability to continuously track triggers and changes as they occur, assessing their probabilities and potential impacts in order to anticipate disturbances and take timely action to avoid or mitigate them	Post-disturbance	12.4%	“Measuring disruptions and resiliency in real time has a great potential, as they can be used to maintain situational awareness of disturbances in the supply chains and their potential effects in real time” (Hallikas <i>et al.</i> , 2023)
Quick and coordinated response	In the event of a disturbance, provide an immediate and coordinated response to control or mitigate the negative consequences and maintain operational continuity	Post-disturbance	10.1%	“The capability to quickly respond to a crisis and disruption is an important determinant of supply chain resilience” (Vanany <i>et al.</i> , 2022)

(continued)

Table A2. Continued

HSC resilience actions	Definition	Implementation phase	Frequency (% of papers citing the action, each paper can cite more than one)	Coded themes examples
Stock optimisation	Efficiently managing inventory levels to balance supply and demand, ensuring adequate stock availability during disruptions	Pre and post-disturbance	10.1%	“The objective of inventory control is to meet the customer demand at the lowest possible cost and to have enough availability of a product even under uncertainties and critical circumstances like disasters” (He and Kokash, 2018)
Multiple transportation modes	A variety of transportation methods, including road, rail, air and sea, as well as alternative routes, to ensure the flexibility and continuity of the supply chain in the event of a disturbance	Pre-disturbance	9.0%	“Adopted the multiple-transportation modes strategy (i.e. employing different types of transportation fleets to transport materials and products) for incorporating the resilience in their SCs” (Nayeri <i>et al.</i> , 2022)
Capacity expansion	Expansion of capacity (e.g. beds, production) to meet increased demand following a disruption	Pre-disturbance	9.0%	“This strategy is used to deal with lost capacities of facilities in the face of disruptions” (Sabouhi <i>et al.</i> , 2018)
Flexible production	Capability of increasing or decreasing production in response to disturbances	Pre and post-disturbance	7.9%	“Resilience is reflected by the ability of manufacturing firms to scale up their production capacity to meet sudden spurts in demand” (Gereffi <i>et al.</i> , 2022)
Facility fortification and dispersion	Strengthens key sites against disruptions and strategically distributes facilities across multiple locations, reducing vulnerability and ensuring operational continuity in the event of localised disturbances	Pre and post-disturbance	6.7%	“Facilities with higher fortification level can maintain higher remaining production capacity after a disruptive event; yet, more fortification costs more” (Sabouhi <i>et al.</i> , 2018)

(continued)

Table A2. Continued

HSC resilience actions	Definition	Implementation phase	Frequency (% of papers citing the action, each paper can cite more than one)	Coded themes examples
Lean management and waste reduction	Streamlining operations by eliminating inefficiencies, minimising resource waste and enhancing the flexibility and robustness of HSC during disruptions	Pre-disturbance	5.6%	“From the elimination of waste through the adoption of lean, it is possible to reallocate resources. Moreover, lean principles adoption can improve resilience by reducing process wastes, simplifying the process routines and reducing the complexities” (Alemsan and Tortorella, 2022)
Data analytics	Analysis and interpretation of data to optimise HSCs’ design and operation, enabling timely and efficient responses to potential disturbances	Pre-disturbance	5.6%	“Expanding scope of applying data analytics in forecasting and distribution [. . .] may help the firm to accurately forecast the demand in the changing market” (Chowdhury <i>et al.</i> , 2021)
Process integration and standardisation	Establishing uniform procedures to collect, analyse and evaluate control information regarding potential risk triggers, enabling proactive management of factors that could lead to systematic disruptions	Pre-disturbance	3.4%	“The process integration capability mitigates HCSC disruptions by smoothening out inventory process flows, safety stock conflicting objectives, and risk information asymmetry” (Friday <i>et al.</i> , 2021)

Table A3. Healthcare supply chain resilience barriers

HSC resilience barriers	Frequency (% of papers citing the barrier, each paper can cite more than one)	Coded themes examples
Lack of resources	23.6%	“In most developing and underdeveloped countries, common limitations are people’s lack of awareness about problems, inefficient processes, and resource shortages, which is also evident in the case of HSO challenges during extreme disruptive events” (Chowdhury <i>et al.</i> , 2024)
Uncertainty	23.6%	“Uncertainty in decision-making is another key challenge for managers in the face of disasters” (Azadi <i>et al.</i> , 2022)
Structural and regulatory complexity	19.1%	“Complexity [...] would also increase the difficulty of coordinating the activities with a negative impact on the probability for undesirable events to occur” (Zaza <i>et al.</i> , 2022)
Lack of data	14.6%	“This pandemic can be considered data-driven [...] if the data is not accurate and verified, the decision made can be wrong” (Sathya and Banik, 2022)
Fragmentation	10.1%	“The provision of fragmented and non-goal-based services can lead to the waste of time and resources during disasters” (Bastani <i>et al.</i> , 2023)
Globalisation	7.9%	“Extending supply chain borders leads to more challenges in supply chain management (SCM) affected by more uncontrolled factors” (Hasani, 2021)

Supplementary material

The supplementary material for this article can be found online.

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