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Lean and Resilience in the healthcare supply chain

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RESUMO

Embora as práticas *lean* tenham sido amplamente adotadas para melhorar a eficiência e a qualidade nas operações de saúde, há preocupações de que essa abordagem possa aumentar a vulnerabilidade a eventos disruptivos e afetar a resiliência. A literatura atual frequentemente trata *lean* e resiliência como conceitos separados, com poucos estudos explorando sua integração na cadeia de suprimentos de saúde, e este trabalho visa preencher essa lacuna. Portanto, o objetivo geral deste trabalho é investigar a integração do *lean management* e da resiliência na cadeia de suprimentos de saúde. Para alcançar esse objetivo, três objetivos específicos foram definidos: (*i*) Identificar a relação entre práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde; (*ii*) Examinar o papel mediador do desenvolvimento da resiliência na associação entre a adoção de princípios *lean* e o desempenho operacional na cadeia de suprimentos de saúde; e (*iii*) Analisar a implementação de práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde em diferentes cenários disruptivos. A metodologia deste estudo consiste em três fases. Na Fase 1, foi realizada uma revisão de escopo para mapear a relação entre práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde. Na Fase 2, uma pesquisa quantitativa foi aplicada a profissionais da cadeia de suprimentos de saúde no Brasil para coletar dados sobre a adoção de princípios *lean,* desenvolvimento da resiliência e o desempenho operacional. Na Fase 3, um estudo de caso foi realizado na cadeia de suprimentos de saúde italiana, visando analisar a aplicação de práticas *lean* e capacidades de resiliência em diferentes cenários disruptivos. Na revisão de escopo, um *framework* foi proposto e destacou as principais práticas *lean,* as principais capacidades de resiliência e os principais fluxos de valor para cada nível da cadeia de suprimentos de saúde. Posteriormente, na Fase 2, as duas hipóteses testadas foram validadas: a adoção de princípios *lean* influencia o desenvolvimento da resiliência, e o desenvolvimento da resiliência medeia a relação entre a adoção de princípios *lean* e o desempenho operacional. Na Fase 3, o estudo de caso mostrou que a aplicação de práticas *lean* e capacidades de resiliência varia conforme o cenário disruptivo. No entanto, a prática de JIT e capacidade de antecipação foram consideradas críticas em quase todas as organizações e cenários estudados. A tese contribui tanto para a teoria quanto para a prática, fornecendo a ligação entre práticas *lean* e capacidades de resiliência, destacando seu potencial sinérgico. Para gestores de saúde, os achados oferecem diretrizes práticas para priorizar e implementar práticas *lean* que aumentem a resiliência. Algumas limitações incluem o tamanho da amostra da pesquisa, restrito a profissionais da cadeia de suprimentos de saúde no Brasil, e o estudo de caso, confinado a organizações italianas, o que pode não captar totalmente os desafios em diferentes contextos. Sugestões para pesquisas futuras incluem realizar estudos comparativos em diferentes países, examinar o papel de paradigmas como Indústria 4.0 e práticas verdes na melhoria da integração de práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde, e realizar entrevistas e grupos focais com profissionais da cadeia de suprimentos de saúde.

Palavras-chave: Produção Enxuta; Resiliência; Organizações de Saúde; Cadeia de Suprimentos.

ABSTRACT

While lean practices have been widely adopted to enhance efficiency and quality in healthcare operations, there are concerns that this approach might increase vulnerability to disruptive events and affect resilience. The current literature often treats lean and resilience as separate concepts, with few studies exploring their integration within the healthcare supply chain and this work aims to fill this gap. Therefore, the general objective of this work is to investigate the integration of lean management and resilience within the healthcare supply chain. To achieve this objective, three specific objectives were defined: (*i*) To identify the relationship between lean practices and resilience capabilities in the healthcare supply chain; (*ii*) To examine the mediating role of resilience development on the association between lean principles adoption and operational performance in the healthcare supply chain; and (*iii*) To analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios. The methodology of this study consists of three phases. In phase 1, a scoping review was conducted to map the relationship between lean practices and resilience capabilities in the healthcare supply chain. In phase 2, a quantitative survey was applied to healthcare supply chain professionals in Brazil to collect data on lean practices adoption, resilience development, and operational performance. In phase 3, a case study was conducted in the Italian healthcare supply chain, aiming to analyze the application of lean practices and resilience capabilities across different disruptive scenarios. The proposed framework from phase 1 highlighted the main lean practices, key resilience capabilities, and main value streams for each level of the healthcare supply chain. Subsequently, in phase 2, the two tested hypotheses were validated: Lean principles adoption influences resilience development, and resilience development mediates the relationship between lean principles adoption and operational performance. In Phase 3, the case study showed that the application of lean practices and resilience capabilities varies depending on the disruptive scenario. However, JIT practice and anticipation capability were considered critical across almost all studied organizations and scenarios. The research contributes to both theory and practice by providing the linking between lean practices with resilience capabilities, highlighting their synergistic potential. For healthcare managers, the findings offer practical guidelines for prioritizing and implementing lean practices that enhance resilience. Some limitations include the survey sample size being restricted to healthcare supply chain professionals in Brazil, and the case study being confined to Italian organizations, which might not capture the challenges across different contexts. Future research suggestions include conducting comparative studies in different countries, examining the role of paradigms such as Industry 4.0 and green practices in enhancing the integration of lean practices and resilience capabilities in the healthcare supply chain, and conducting interviews and focus groups with healthcare supply chain professionals.

Keywords: Lean; Resilience; Healthcare Supply Chain.

RESUMO EXPANDIDO

Introdução

Embora as práticas *lean* tenham sido amplamente adotadas para melhorar a eficiência e a qualidade das operações de saúde, há preocupações de que essa abordagem possa aumentar a vulnerabilidade a eventos disruptivos. Nesse sentido, o conceito de resiliência na cadeia de suprimentos emerge, que se refere à capacidade de preparar-se para eventos inesperados, responder a eles e recuperar a continuidade das operações. A literatura atual frequentemente trata *lean* e resiliência como conceitos separados, com poucos estudos explorando sua integração na cadeia de suprimentos de saúde. Este trabalho busca preencher essa lacuna ao investigar como a implementação de práticas *lean* pode influenciar o desenvolvimento de capacidades de resiliência. A pesquisa aborda três questões de pesquisa: (*i*) Qual é a relação entre práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde? (*ii*) Como o desenvolvimento da resiliência influencia a associação entre a adoção de princípios *lean* e o desempenho operacional na cadeia de suprimentos de saúde? (*iii*) Como a implantação de práticas *lean* e capacidades de resiliência varia na cadeia de suprimentos de saúde em diferentes cenários disruptivos?

Objetivos

O objetivo geral deste trabalho é investigar a integração do *lean management* e da resiliência dentro da cadeia de suprimentos de saúde. Para alcançar este objetivo, foram definidos três objetivos específicos: (*i*) Identificar a relação entre práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde;(*ii*) Examinar o papel mediador do desenvolvimento da resiliência na associação entre a adoção de princípios *lean* e o desempenho operacional na cadeia de suprimentos de saúde e (*iii*) Analisar a implementação de práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde em diferentes cenários disruptivos.

Metodologia

A metodologia deste estudo é composta por três fases distintas. Na Fase 1, foi conduzida uma revisão de escopo para mapear a relação entre práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde. Essa revisão incluiu uma análise de 44 artigos selecionados a partir de cinco bases de dados. Na Fase 2, uma pesquisa quantitativa foi aplicada a profissionais da cadeia de suprimentos de saúde no Brasil, utilizando um questionário para coletar dados sobre a adoção de práticas lean, o desenvolvimento da resiliência e o desempenho operacional. Foram obtidas 123 respostas válidas para testar três modelos utilizando técnicas estatísticas a fim de validar duas hipóteses. Na Fase 3, foi realizado um estudo de caso na cadeia de suprimentos de saúde italiana, com o objetivo de analisar a aplicação de práticas *lean* e capacidades de resiliência em diferentes cenários disruptivos. O estudo envolveu 100 pessoas de quatro organizações separadas em três níveis da cadeia de suprimentos de saúde (um produtor de medicamentos, uma distribuidora de medicamentos e dois hospitais) ligados pelo fluxo de medicamentos. Além disso, especialistas de *lean supply chain* avaliaram cada uma das práticas lean e capacidades de resiliência para cada um dos cenários. Com esses dados, foi possível avaliar as práticas lean e capacidades de resiliência mais criticas para cada um dos cenários.

Resultados
Os resultados da revisão de escopo na Fase I indicaram que a integração de práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde é um tema emergente. A análise revelou que nenhum estudo abordou todos os três níveis cadeia simultaneamente. O fluxo de valor mais frequentemente estudado foi o de consumíveis médicos, enquanto os fluxo menos estudados foram o de informações. A análise de relevância de 234 relações entre práticas *lean* e capacidades de resiliência indicou que: 16 relações foram altamente relevantes e 83 relações foram moderadamente relevantes. Além disso, o framework proposto trouxe as principais praticas *lean*, principais capacidade de resiliência, e principais fluxo de valor para cada um dos níveis da cadeia de suprimentos de saúde. Posteriormente, na Fase II, a partir dos dados do questionário aplicado para trabalhadores da cadeia de suprimentos de saúde do Brasil, mostrou que as duas hipóteses testadas foram validadas. Ou seja, a adoção dos princípios *lean* influencia o desenvolvimento da resiliência, e o desenvolvimento da resiliência medeia a relação entre a adoção de princípios *lean* e o desempenho operacional. Em relação as variáveis de controle, o nível da cadeia teve relação significativa e o tamanho da organização não teve relação significativa. Já na Fase III, o estudo de caso mostrou que a aplicação de práticas *lean* e capacidades de resiliência varia dependendo do cenário disruptivo. Entretanto, a prática JIT e antecipação foram consideradas críticas (baixa adoção porém importante a partir das avaliações de especialistas) em praticamente todas as organizações estudadas e todos os cenários.

Conclusões
O objetivo geral e os objetivos específicos foram atingidos por meio das três fases do trabalho. Algumas limitações do trabalho podem ser destacadas. A revisão de escopo utilizou cinco bases de dados, o que pode ter excluído artigos relevantes. O tamanho da amostra da pesquisa, restrito a profissionais da cadeia de suprimentos de saúde no Brasil na Fase II, e o estudos de caso, confinados a organizações de saúde italianas na Fase III, podem não capturar toda a diversidade de práticas e desafios em diferentes contextos. A cadeia de suprimentos de saúde foi classificada em apenas três níveis, o que pode não refletir todas as complexidades do setor. Além disso, o estudo de caso foi limitado a quatro organizações. Como sugestões para estudos futuros, orienta-se conduzir estudos comparativos em diferentes países e regiões para entender como variações culturais e políticas impactam a integração de práticas *lean* e capacidades de resiliência. Adicionalmente, examinar o papel de outros paradigmas, como Indústria 4.0 e práticas verdes, na melhoria da integração de práticas *lean* e capacidades de resiliência na cadeia de suprimentos de saúde. Por último, realizar entrevistas e grupos focais com profissionais da cadeia de suprimentos de saúde para aprofundar a compreensão de suas percepções e experiências na implementação de *lean* e resiliência.

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1 INTRODUCTION

1.1 CONTEXTUALIZATION

The supply chain comprises a combination of processes aimed at meeting customer requests, which include entities such as suppliers, manufacturers, transporters, warehouses and customers (Tiwari *et al*., 2021). More specifically, healthcare supply chain includes the business activities and operations necessary for the production, handling, storage and distribution of supplies (drugs, medical consumables, etc.) from suppliers to customers (Lucchese *et al.,* 2020). Healthcare supply chain is known by a high complex system and high costs involved (Kannampallil *et al.,* 2011; Skowron-Grabowska *et al*., 2022). Therefore, the quality of this type of service must be guaranteed since it involves patients' health, even though the available resources are usually limited (Alowais *et al*., 2023).

In order to increase the efficiency and quality of healthcare supply chain operations, lean practices have been applied (Khorasani *et al*., 2020). Lean practices aim to organize activities to produce more added value and eliminate waste (Tortorella *et al*., 2017). The lean practices implementation brings many benefits, such as increased efficiency, minimum stocks and higher productivity. However, lean practices implementation can leave the supply chain more vulnerable to unexpected events (Lotfi; Saghiri, 2018). The vulnerability occurs because erroneous waste elimination can remove critical buffers needed to handle disruptions (Maslaric *et al*., 2013). Therefore, in contrast to lean practices implementation, the concept of resilience emerges.

Resilience has been studied extensively from ecological, social and organizational perspectives (Bhamra *et al*., 2011), but has started to spread in the literature on supply chain management and is considered an emerging topic (Purvis *et al*., 2015; Zavala-Alcívar *et al.,* 2020). Ponomarov and Holcomb (2009) define supply chain resilience as the chain's ability to prepare for unexpected events and respond to disruptions by recovering business continuity at the desired level in order to ensure business continuity. Supply chain resilience focuses on the adaptive capacity of the system to cope, recover and adjust to temporary disruptive events (Kamalahmadi; Parast, 2016). Therefore, the focus on supply chain resilience has gained increasing interest from supply chain managers and academics due to significant incidents that happen worldwide (Mohammed *et al*., 2019).

In this sense, healthcare organizations and their partners must develop resources that can protect their operations in the event of disruption in order to increase their resilience (Mandal, 2017). The resilience becomes fundamental in the supply chain of healthcare organizations due to the criticality of their services and the vital consequences that possible failures may cause (Zamiela *et al.,* 2022). For example, epidemics, pandemics and natural disasters can disrupt the supply of materials (Golan *et al.,* 2020). Therefore, some actions are necessary for the supply chain to be better prepared for unforeseen events, which are often considered wasteful from a lean perspective.

There seems to be a conflict between the lean and resilience paradigms, as both seek objectives that, at times, may require opposite actions (Ruiz-Benítez *et al*., 2018). Increasing resilience to address types of vulnerabilities can often drive up operating costs. On the other hand, the organization can improve its resilience with the help of lean practices implementation since its processes will be better understood, and thus generate greater control in the reaction to some disruptive event (Ivanov, 2021). Therefore, it is necessary to develop a new commitment for companies, to ensure that their supply chains are less vulnerable to risks and that they continue to maintain their lean benefits (Birkie, 2016). Only a complete understanding of the relationship between lean practices implementation and resilience can contribute to a more efficient and less vulnerable supply chain (Maslaric *et al*., 2013; Habibi Rad *et al.,* 2021).

Based on the arguments described above, the following research questions were formulated:

(*i*) What is the relationship between lean practices and resilience capabilities in the healthcare supply chain?;

(*iii*) How does resilience development influence the association between lean principles adoption and operational performance in healthcare supply chain?;

(*iii*) How does the deployment of lean practices and resilience capabilities vary within the healthcare supply chain across different disruptive scenarios?

1.2 JUSTIFICATION

The importance of studies aimed at integrating lean implementation and resilience in the healthcare supply chain occurs both in academic and practical perspectives. From an academic perspective, some studies address the impact of lean practices on resilience in the healthcare supply chain. For example, Yilmaz *et al*. (2023) studied the lean practice adoption of Value Stream Mapping (VSM) to improve resilience in the distribution of medicines to a hospital. Similarly, Rosso and Saurin (2018) used VSM to enhance resilience in an intensive care unit. Hundal *et al.* (2021) concluded that Lean Six Sigma improves organizational resilience through efficient, reliable, and resilient processes. The application of Lean Six Sigma tools and techniques is crucial for both proactive and reactive responses to the impacts of COVID-19 in hospitals (Hundal *et al.,* 2021). It is evident that there are recent findings on the benefits of this integration; however, no studies were found addressing the impact of lean practices implementation on resilience in the healthcare supply chain in an integrated manner. Therefore, this study will increase the body of knowledge in the area under study.

From a practical perspective, disruptive events are happening with more frequency and demanding rapid answers. For example, the COVID-19 pandemic has proved to be one of the most disruptive events, affecting citizens and organizations alike, it has had an unprecedented impact on operations of healthcare supply chain (Leite *et al.,* 2021). Although lean practices implementation has benefits in healthcare operations and supply chain, a disruptive event as the pandemic affects its efficiency by reducing capacity, creating unbalanced demand and disruptions in processes (Tortorella *et al*., 2022). This disruptive impact on healthcare operations has raised many questions about the applicability and capacity of lean healthcare processes to respond to critical events (Ivanov, 2021). Birkie (2016) states that studying the phenomenon between lean and resilience in the supply chain is relevant because possible interruptions are becoming more expensive. In addition, Chopra and Sodhi (2014) mention that resilience against disruptions is becoming a top priority issue for many organizations, as it is an effective way to mitigate disruptions. Therefore, the trade-offs between lean and resilience in the supply chain must be examined in detail, particularly in the highly complex healthcare supply chain, where these aspects can vary significantly (Maslaric *et al*., 2013; Nunes-*Vaz et al.,* 2019).

1.3 OBJECTIVES

The general objective of this thesis is to investigate the integration of lean management and resilience within the healthcare supply chain. To achieve this objective, three specific objectives are proposed, as described below:

a) To identify the relationship between lean practices and resilience capabilities in the healthcare supply chain;

b) To examine the mediating role of resilience development on the association between lean principles adoption and operational performance in healthcare supply chain;

c) To analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios.

1.4 STRUCTURE OF THE THESIS

The structure of the thesis is divided into seven chapters and is illustrated in Figure 1. The current chapter aims at introducing the main subject of this thesis along with the central research questions that this thesis worked on. Besides the contextualization section, the general and specific objectives of this study are clearly stated. In addition, the justification, the structure and the delimitations of the thesis are defined.

Chapter 2 presents the methodological structure of the thesis. In this chapter, the thesis is classified in relation to the reasoning (deductive or inductive). In addition, each phase of the thesis is classified in relation to the objective (e.g., exploratory, descriptive or explanatory), in relation to the nature (basic or applied) and finally in relation to the methodological procedure (e.g., survey, case study, etc.). Furthermore, the objective of this chapter is to connect the different phases and stages of the thesis in order to achieve the general objective of the work.

The thesis consists of a compendium of three articles resulting from the three phases in which the work will be conducted. Chapter 3 comprises the first phase of the work that originates the first article of the compendium. In this chapter, the first specific objective is achieved through a scoping review and leads to the following article: “Lean and Resilience in the Healthcare Supply Chain – A Scoping Review”. Chapter 4 comprises the second phase of the work that originate the second article of the compendium. In this chapter, the second specific objective is achieved through a survey and originate the following article: “Lean and Resilience in the Healthcare Supply Chain: A Mediation Analysis”. Chapter 5 comprises the third phase of the work and the third specific objective is achieved through a case study and originate the following article: “Integrating lean and resilience – a healthcare supply chain perspective. Finally, Chapter 6 presents the general results and Chapter 7 the general conclusions, by addressing all the proposed research questions and objectives. This chapter also discusses the limitations of this work and opportunities for future research.

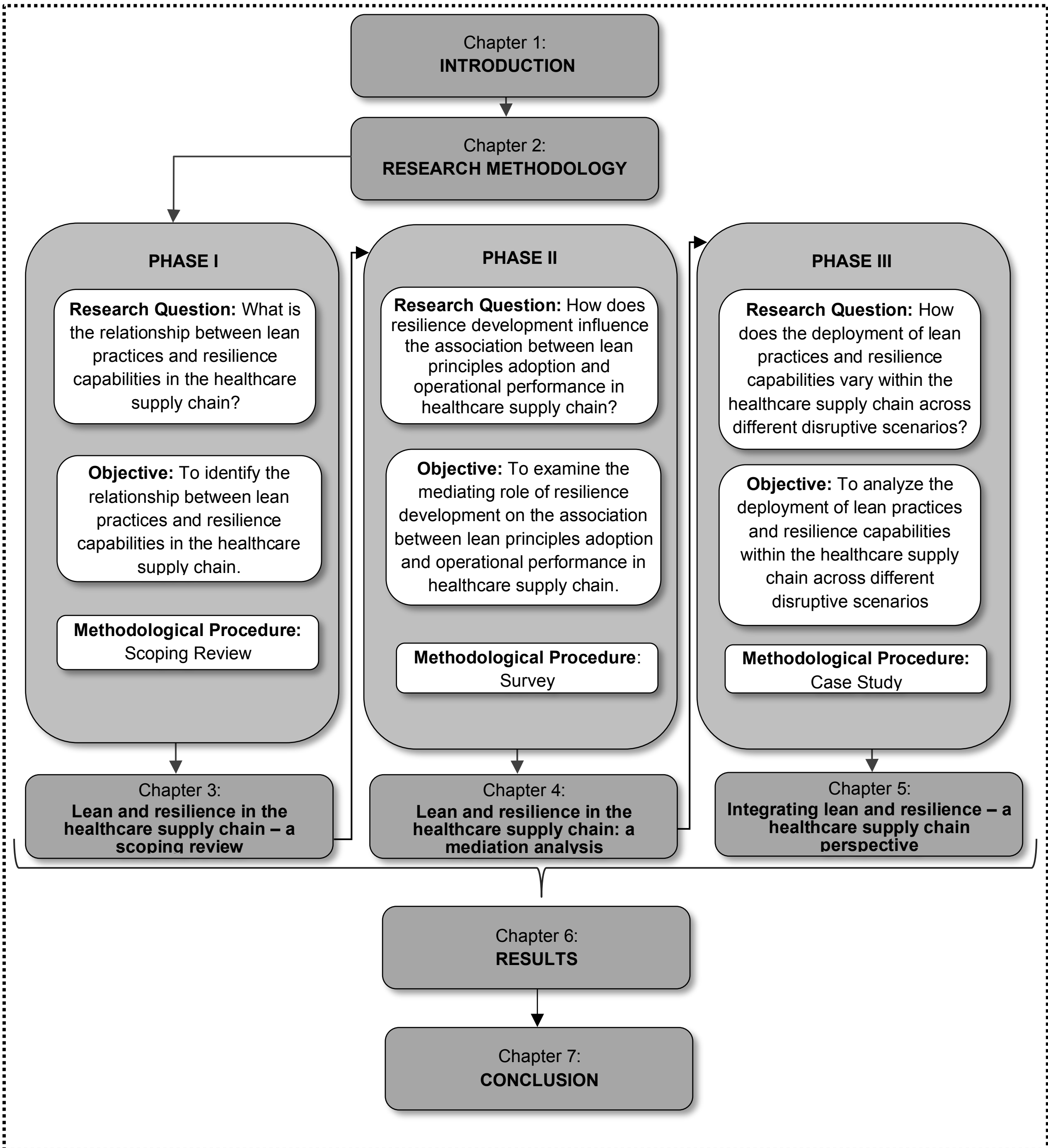

Figure 1 - Thesis Structure

1.5 DELIMITATIONS

In this section, the delimitations of the thesis are presented according to each phase of the work. In Phase 1, during the scoping review procedure, only articles published in journals are selected, excluding conference articles. In addition, five important databases are used, but there is a risk that important articles exist outside these databases. The selected articles are analyzed through the lean practices used, resilience capabilities, value stream and tier level of healthcare supply chain. In this way, other possible content analyzes are out of scope. Regarding the tier levels, the healthcare supply chain is classified into three levels, so another number of divisions could be used. In addition, as there is a dispersion regarding the definitions of resilience and lean practices in the healthcare supply chain, three publications are used as a basis for the work.

In Phase 2, for the survey procedure, the questionnaire was applied only to people working in the healthcare supply chain in Brazil. In addition, the survey was divided into three constructs: lean principles adoption, resilience development, and operational performance, although additional constructs could have been used. The analysis of the collected data was limited to quantitative and statistical techniques, excluding qualitative analyses that could complement the interpretation of the results.

In Phase 3, the case study is focused on the Italian healthcare supply chain, and three tier levels were chosen for analysis. Therefore, the scope is limited to the supply chain of this country and exclusively to the flow of drugs. Additionally, the sample was limited to 100 participants within 4 organizations. Regarding disruptive scenarios, they could be classified in various ways, such as by origin or duration, but consequences and probability of occurrence were considered.

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2 RESEARCH METHODOLOGY

In this chapter, the methodological structure of the thesis is presented. First, in general terms, the thesis is classified as deductive reasoning. Deductive reasoning is characterized by starting the research from general ideas and concluding generated specific findings based on utilizing currently available theories (Evans, 2015). The deductive reasoning expands on an already explored area of knowledge or combines different areas of research in order to enhance the current understanding of a certain phenomenon (Johnson-Laird, 2010). This is the case of the present thesis that brings together two themes that are more consolidated in the literature: lean and resilience, in a combination that still needs to be explored from the perspective of the healthcare supply chain. Research with deductive reasoning sequentially processes unrefined general knowledge into more refined and specific knowledge (Evans, 2015). In the case of this thesis, it starts with a scoping review to familiarize with the theme of lean and resilience in the healthcare supply chain, considered an emerging topic. Subsequently, hypotheses are defined from the literature to be empirically tested through a survey. Finally, a case study will be held to consolidate previous results and generate additional knowledge.

Now, each phase of the thesis is classified in relation to the research objective, research nature and methodological procedure. The objective of phase I is to identify the relationship between lean practices and resilience capabilities in the healthcare supply chain. The relationship between lean and resilience is not yet established and is considered an emerging topic as it has little scientific evidence even more when researching the healthcare supply chain. Therefore a scoping review will be conducted because is an appropriate methodological procedure to determine the scope of a body of emerging topics when evidence is still unclear (Muun *et al.,* 2018). The scoping review has become an increasingly popular approach for synthesizing research evidence (Pham *et al.,* 2014). Therefore, it is interesting that, for the development of the thesis, the relationship of this emerging topic is identified in order to later use other methods and bring additional contributions.

The first phase of the research has an exploratory objective. When the research is in the preliminary phase, it aims to provide more information on the subject to be investigated, enabling its definition and design, which characterizes exploratory research (Swedberg, 2020). This is the case of the first phase of the thesis, which because of the lack of in-depth knowledge of the phenomenon investigated, it is necessary to define the problem, to clarify one's situations and establish an overview. Regarding nature, the first phase is classified as basic research. The basic research is a systematic investigation set to achieve a better and more detailed understanding of a research subject or phenomenon and not to solve a specific problem (Gulbrandsen; Kyvik, 2010). In other words, the basic research has the objective of acquire new knowledge that contributes to the advancement of science, without a specific practical application (Calvert, 2006). Thus, this type of research serves as a basis for the development of applied research.

After the knowledge and immersion in the theme from the scoping review in phase I, phase II begins with the survey as the methodological procedure. This method is chosen to achieve the following specific objective: to examine the mediating role of resilience development on the association between lean principles adoption and operational performance in healthcare supply chain. The Survey has some advantages such as direct knowledge of reality, economy, speed and quantification (Forza, 2002). In this way, through the survey, it is possible to achieve the objective based on responses from employees of companies belonging to the healthcare supply chain in Brazil.

Regarding the objective, phase II is classified as descriptive research. A descriptive research seeks to discover the frequency with which an event occurs, its nature, its characteristics, causes, relationships with other events through interviews, forms, questionnaires, etc. based on a large representative sample (Grimes; Schulz, 2002). Furthermore, the major difference between exploratory and descriptive research is that the second is characterized by an earlier formulation of specific hypotheses (Van Wyk, 2012). This is in line with phase II, where hypotheses are formulated based in the literature and tested from the questionnaire with a sample of 123 responses. Regarding nature, the second phase is classified as applied research. Applied research is primarily concerned with examining empirical evidence for answers while in basic research, the researcher examines data samples in order to gather more information about them (Gulbrandsen; Kyvik, 2010). After carrying out applied research by testing the empirical evidence, the findings validations will confirm or negate the research hypotheses (Dul *et al.,* 2010). This is the case of Phase II that validates two hypotheses from the data survey analysis.

Despite the benefits of a survey, this method has some disadvantages. One of the disadvantages is that the survey has little depth in the study and, therefore, other research methods can be used for a more detailed and deeper study. Thus, phase III of the development of the thesis comes to complement the previous phase. The third specific objective is to analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios. The methodological procedure used is case study in the Italian healthcare supply chain. Case Study can confirm insights obtained from other methodologies (Yin *et al*., 2012), such as those used in the previous phases of the thesis. Surveys and questionnaires can give researchers some hard data to use when evaluating a specific concept, while case studies allow for more in-depth exploration of individual cases to create new approaches (Yin *et al*., 2012).

It is important to notice that most research studies begin with exploratory research, descriptive research, and then explanatory research (Akhtar, 2016). This thesis follows the same logic. Therefore, phase III is classified as explanatory research. An explanatory research is an attempt to explain why certain phenomena works and explains the patterns of relationships between variables (Van Wyk, 2012). This type of research study seeks to combine different ideas in order to understand the nature of cause and effect relationships (Bertrand; Fransoo, 2002). Regarding nature, the third phase is classified as applied research in the same way as phase II. The research will be applied because the scope is to provide clear solutions to practical problems (Check; Schutt, 2012) and the research is conducted in real-life settings (Yin *et al*., 2012). Figure 2 summarizes the methodological structure explained in this chapter.

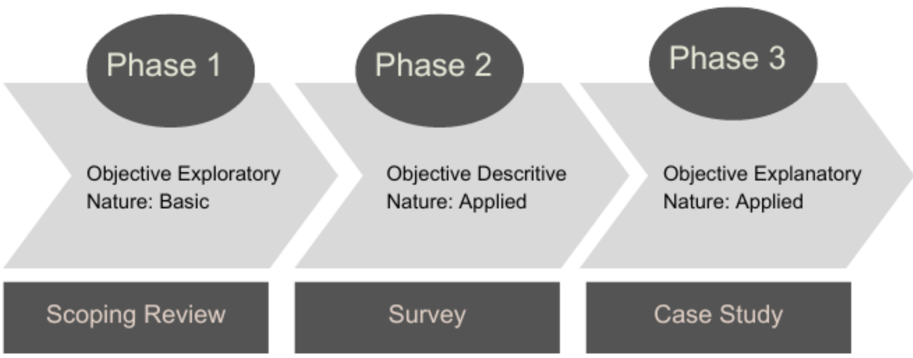

Figure 2 - Research Classification

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3 LEAN AND RESILIENCE IN THE HEALTHCARE SUPPLY CHAIN – A SCOPING REVIEW*

Abstract: The importance of a lean healthcare supply chain is increasingly discussed. However, it is still not very clear how lean practices relate to resilience capabilities, as there are synergies and divergences between them. Therefore, this article aims at identifying the relationship between lean practices and resilience capabilities in the healthcare supply chain. A scoping review was conducted based on five databases, which allowed the content analysis of 44 articles. Such analysis allowed the verification of trends and volume of studies on this topic. Further, the descriptive numerical and thematic analyses enabled the proposition of a conceptual framework, relating the adoption of lean practices to the development of resilience capabilities according to the tiers of the healthcare supply chain in different value streams. To the best of our knowledge, there is no similar study in the literature. In practical terms, the understanding of these relationships provides healthcare managers arguments to prioritize the application of lean practices to improve desired resilience capabilities in the entire healthcare supply chain. Further, three research directions were derived from this scoping review: (*i*) empirical validation of the contribution of lean practices to resilience capabilities in the healthcare supply chain, (*ii*) systemic implementation of lean practices across tier levels of the healthcare supply chain, and (*iii*) complementary approaches to lean implementation towards a more resilient healthcare supply chain.

Keywords: Lean healthcare; Resilient healthcare; Healthcare supply chain; Scoping review.

3.1 INTRODUCTION

The constant pressure for more efficient processes is increasing the interrelationship between organizations and their supply chains (Carvalho *et al.,* 2017). In this context, supply chain integration and collaboration has been facilitated by the development of lean practices on supply chain (Golan *et al*., 2020). Lean supply chain can be defined as a set of organizations directly linked by upstream and downstream flows of products, services, information, and funds that collaboratively work to reduce cost and waste by efficiently pulling what is needed to meet the needs of customers (Tortorella *et al.,* 2017). The implementation of lean practices can also increase efficiency and flexibility of operations, minimizing lead time and maximizing the

*This chapter presents the first article of this thesis. The article has been published in the International Journal of Lean Six Sigma.

resources utilization (Breen *et al.,* 2020). However, a misguided waste elimination might exaggeratedly reduce important slacks in the supply chain, letting them more vulnerable to disruptive events (Kurniawan *et al*., 2017; Ruiz-Benitez *et al.,* 2018). Major disruptions, such as financial crises, pandemics, or even natural events (e.g., tsunamis, floods, and cyclones) reveal a lack of preparation of the supply chain from many sectors, including the healthcare supply chain (Heckmann *et al.,* 2015).

More specifically, healthcare organizations and their suppliers, partners, and stakeholders must develop countermeasures that can protect their operations in the occurrence of a disruption, so that their resilience is enhanced (Mandal, 2017). Ponomarov and Holcomb (2009, p.131) define supply chain resilience as “the chain's ability to prepare for unexpected events and respond to disruptions by recovering business continuity at the desired level in order to ensure business continuity”. Resilience is a fundamental aspect in the healthcare supply chain due to the criticality of their services and the vital consequences that unexpected disruptions may cause (Achour *et al*., 2010; Achour *et al.,* 2011; De Vries; Huijsman, 2011). One way to understand resilience is through resilience capabilities (Brusset *et al.,* 2017). Resilience capabilities are attributes that enable organizations to prepare for and respond to disruptions effectively (Pettit et al., 2013). However, developing resilience capabilities can sometimes lead to higher operational cost (Purvis et al., 2015).

At a first glance, lean practices and resilience capabilities might lead to conflicting outcomes for the healthcare supply chain. In fact, Cabral *et al.* (2012) argue that there are synergies and divergences between lean practices and resilience capabilities. However, Purvis *et al.* (2015) stated that there is a lack of understanding regarding how organizations overcome these trade-offs between lean and resilience. Most studies on supply chain approach these topics individually, without explicitly discussing their concurrent effects (Gonvidan *et al*., 2013). For instance, Costa *et al.* (2016), Borges *et al*. (2019), Parkhi *et al.* (2019), and Khorasani, et al. (2020) focused their reviews on the lean implementation in healthcare supply chains, while De Lima *et al*. (2018) and Golan *et al*. (2020) discussed resilience development in the same context. Therefore, studies that comprehend the relationship between lean practices and resilience capabilities could contribute to the development of more efficient and less vulnerable healthcare supply chains (Maslaric *et al*., 2013).

Based on the previous arguments, a research question was formulated: “What is the relationship between lean practices and resilience capabilities in the healthcare supply chain?" Therefore, this article aims at examining the relationship between lean practices and resilience capabilities in the healthcare supply chain. For that, a scoping review was conducted, which is an ideal method to determine the scope or coverage of a body of literature on a given topic. Scoping review provides clear indication of the volume of literature and studies available, as well as an overview of their focus, identifying emerging topics when evidence is still unclear (Muun *et al.,* 2018). This study contributes to both theory and practice. Regarding the theoretical perspective, this study conceptually proposes the relationships between lean practices and resilience capabilities in the healthcare supply chain, whose understanding is still vague and scattered. In terms of practical contributions, the identification of these relationships provides managers arguments to prioritize the application of lean practices that are more prone to improve the desired resilience capabilities in the healthcare supply chain. This supports assertive decisions towards a leaner and more resilient healthcare supply chain.

3.2 BACKGROUND

3.2.1 Lean healthcare

Lean healthcare consists of a management approach for continuously improve healthcare based on a set of practices and principles adapted from the Lean Manufacturing (Erthal *et al*., 2021). The first reports on lean healthcare date back from the early 2000s (D'andreamatteo *et al*., 2015), and its main principles are: (*i*) identify what is of value to the patient; (*ii*) map value flow by identifying value-added and non-value-added activities to patient care; (*iii*) establish a continuous flow within each part of the health chain; (*iv*) establish pull system from the patient to providers; and (*v*) seek perfection by improving processes and delivering excellent services to patients (Borges *et al.,* 2019). Lean healthcare supports the achievement of an increasingly accurate service to patients (Teixeira et al., 2021). The positive impact of lean healthcare on healthcare performance has been widely evidenced (e.g., Kim *et al*., 2005; D'andreamatteo *et al.,* 2015), especially in terms of productivity and cost efficiency, clinical quality, patient and staff safety and financial results.

It is also worth mentioning that lean healthcare has been applied in different tier levels of the healthcare supply chain. Papalexi et al. (2020) proposed dividing the healthcare supply chain into three tier levels: upstream domain (tier level 1), central domain (tier level 2) and downstream domain (tier level 3). Tier level 1 grouped manufactures of health materials, tier level 2 included distributors, suppliers and hospital warehouses, and tier level 3 encompassed the healthcare providers, such as hospitals and medical clinics. At tier level 1, Sieckmann *et al*. (2018) and Byrne *et al*. (2021) applied lean principles in medicine manufacturing to reduce costs and increase process quality, while Narayanamurthy et al. (2018) investigated the readiness of suppliers for lean implementation. At tier level 2, Alshahrani *et al.* (2018) studied the logistics integration between hospitals and suppliers. At tier level 3, lean healthcare has been used in highly complex departments, such as improving the readiness of emergency departments (Alnajem *et al.,* 2019) and improving strategic planning in surgical units (Sales; Castro, 2021). Although lean healthcare is characterized as irregular and fragmented (Young *et al.,* 2008), some authors (e.g., Adebanjo *et al*., 2016; Borges *et al*., 2019) have listed the most commonly applied practices in the healthcare supply chain; they are: value stream mapping (VSM), visual management, A3, standardized work, pull system, kanban, 5S, departmental layout, vendor managed inventory (VMI), inventory management, spaghetti diagram, just-in-time (JIT), continuous improvement, kaizen, radio frequency identification (RFID), autonomation, six-sigma and poka-yoke.

3.2.2 Resilient Healthcare

Resilience has been studied from different perspectives, such as ecological, social, and organizational (Bhamra *et al*., 2011), but its diffusion to the healthcare sector has recently occurred (Purvis *et al*., 2015). Resilience healthcare is well defined by Hollnagel (2013, p.6) as ‘the ability of the healthcare system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under both expected and unexpected conditions’. Considering that pandemic, natural disasters and social, economic, and political conflicts can affect the healthcare sector (Marmolejo-Saucedo *et al*., 2020), resilience plays an extremely important role to cope with the implications from those issues (Mandal, 2017).

Healthcare resilience has been approached in different ways in the literature. For example, Haghighi and Torabi (2018) proposed a resilience framework for hospital information systems. Similarly, Ross *et al.* (2019) analyzed an integrated dataset to enhance the resilience of an emergency department. McCann *et al.* (2013) studied the development of environments that promote resilience through healthcare practitioners, and García-Izquierdo *et al.* (2018) investigated the role of resilience in the psychological health of nurses. Bergerød *et al.* (2020) provided new insights to resilience performance in the treatment of severe diseases.

Additionally, to mitigate disruptions beyond the healthcare organization frontiers, healthcare managers are increasingly concerned with building a more resilient healthcare supply chain (Rui-Benitez *et al.,* 2018). Berg *et al.* (2018) found that studies on healthcare resilience have been predominantly conducted at the micro level (i.e., frontline clinical staff), while research at the macro and meso levels (i.e., hospitals and healthcare supply chain, respectively) are much scarcer. This highlights the need for further studies holistically involving the healthcare supply chain.

3.3 RESEARCH METHOD

To achieve the objective of the phase, a scoping review was conducted, which is an appropriate method to determine the scope of a body of emerging topics when evidence is still unclear (Muun *et al.,* 2018). The research method comprised four steps: (*i*) definition of research question, (*ii*) determination of the corpus of articles, (*iii*) descriptive and content analyses, and (*iv*) relevance level and framework proposition.

In step (*i*), it was defined the research question so that the scope of this study could be determined, and ambiguity avoided (Muun *et al.,* 2018). A short review was made in Scopus database to allow a better understanding of the research scope and terms selection (Tranfield *et al.,* 2003). It was noted that lean practices have been studied in the healthcare supply chain in the last two decades. However, when the resilience is sought simultaneously, literature evidence becomes scarcer. Based on this inference, one research question was formulated:

RQ. What is the relationship between lean practices and resilience capabilities in the healthcare supply chain?

The second step sought to determine the corpus of articles. For that, a comprehensive search in five databases (Web of Science, Scopus, Pub Med, Emerald Insight and Science Direct) as recommended by studies with similar approach (e.g., Volland *et al*., 2017; Augusto; Tortorella, 2019) was carried out during May 2021. The search was conducted in titles, keywords or abstracts that included the terms ("health*)

AND (“supply chain”) AND (“lean” OR “resilien*”), which resulted in 572 publications (see Table 1). Following recommendations by Tortorella et al. (2020), ten recent publications from the past five years were randomly selected and had their keywords compared with the ones initially used. Ten publications from the past five years were randomly selected and their keywords were compared with the ones used in the initial search, as recommended by Tortorella *et al.* (2020). It was verified that the terms are included in keywords in these articles and no additional keywords were necessary.

Publications were included/excluded after meeting pre-defined criteria, as suggested by Borges *et al.* (2019): (*i*) exclusion of duplicate articles, exclusion of articles not written in English, and solely inclusion of articles published in peer-reviewed journals; and inclusion of articles whose (*ii*) title, (*iii*) abstract and (*iv*) full content were aligned with the research topic. After applying these criteria to the screening process, 40 publications from the initial sample remained. A backward snowballing procedure was performed to identify possible relevant articles (Badampudi *et al.,* 2015) using the reference list of the 40 articles. If a reference was included in more than one article, then a full content analysis was carried out for verifying alignment. This procedure added 4 articles to the final corpus, resulting in 44 publications.

Table 1 - Screening of publications

Keywords	Database	Initial search	Exclusion of duplicate papers	Title alignment	Abstract alignment	Full content alignment	Snowballing procedure
(“health”) AND (“supply chain”) AND ((“lean”) OR (“resilien*”)	Web of Science	226					
	Scopus	214	**438**	**180**	**85**	**40**	**44**
	Pub Med	61					
	Emerald Insight	37	(-164)	(-258)	(-173)	(-133)	(+4)
	Science Direct	34					
	Total	572					

The third step comprehended the descriptive and content analyses, which were divided into two main stages. In the first stage, it was made a numerical analysis of the content of the articles. The 44 articles were analyzed for the following attributes: year of publication, authors, journals, and supply chain tier levels (Papalexi et al., 2020). In the second stage, a qualitative analysis of the latent content of those articles was performed. For that, three axes were examined by frequency of citation: (*i*) application of lean practices per tier levels of healthcare supply chain, (*ii*) application of lean practices according to different healthcare value streams, and (*iii*) resilience capabilities benefited by lean practices adoption. To frame this qualitative analysis, we used the lean practices proposed by Borges *et al*. (2019) and Adebanjo *et al.* (2018), the tier levels of healthcare supply chain suggested by Papalexi *et al.* (2020), the healthcare value streams suggested by Lowe (2013) (i.e., patients, workers, drugs, medical consumables, medical equipment, information, and services), and the resilience capabilities validated by Pettit *et al*. (2013) (i.e., flexibility, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security/safety, and financial strength. However, if other lean practices, value streams and resilience capabilities were found, they were systematically added to the analysis.

The content analysis allowed the execution of fourth step: the relevance level and the proposition of a conceptual framework relating lean practices and resilience capabilities. The relevance level was used to represent the contribution that the adoption of each lean practice had to the development of each resilience capability at the healthcare supply chain. Three criteria were considered to determine the relevance level: (*i*) citation frequency of lean practices as contributors to each resilience capability, (*ii*) pervasiveness of lean practices across tier levels of the healthcare supply chain, and (*iii*) application of lean practices in different healthcare value streams. Based on an adaptation of Pagliosa *et al*.'s (2019) indications, all criteria were assessed with scores ranging from 0 to 3.

For the criterion (*i*), a score of '0' meant that no evidence was found for the relationship between a given lean practice and a specific resilience capability; a score of '1' indicated that the relationship between a given lean practice and resilience capability was mentioned by up to one third of the citations; for pairwise relationships whose frequency of citations varied between 33.3% and 66.7% a score of '2' was assigned; and a score of '3' was determined for pairwise relationship mentioned by more than two thirds of the works. For the second criterion, '0' indicated that the lean practice was not evidenced in any of the three tier levels; '1' referred to lean practices applied at only one of the tiers; '2' denoted a lean practice adopted at two tiers; and a score of '3' was assigned to lean practices applied in all tier levels. For criterion (*iii*), lean practices that were not applied in any of the healthcare values streams received a score of '0'; lean practices adopted in up to one third of the considered healthcare value streams (i.e., two value streams) were assigned a score of '1'; a score of '2' was determined for lean practices whose citations varied between one third and two thirds of the number of healthcare value streams (i.e., between 2 and 4); and '3' indicated lean practices used in more than two thirds of the listed healthcare value streams. The sum of the scores of each criterion for each pairwise relationship between lean practices and resilience capabilities resulted in the overall relevance level given by *r*. Scores that ranged between ‘0’ and ‘3’ indicated a low contribution of the lean practice to the development of the resilience capability in the healthcare supply chain. Scores that varied between ‘4’ and ‘6’ indicated a moderate relevance of a specific lean practice to the resilience capability. Scores from ‘7’ to ‘9’ indicated a high relevance of the pairwise relationship and, hence, should be prioritized by the healthcare supply chain.

3.4 RESULTS

3.4.1 Descriptive numerical analysis

Figure 3 presents the frequency of publications per year. It is evident that this is an emerging topic whose interest has been growing over the last few years, with its peak of publications occurring in 2019. Regarding the main outlets that have been publishing this topic, Table 2 indicates that eight stood out with at least two publications each. The remaining works were scattered published in another 25 journals. It is worth noting the interdisciplinary nature of those journals, since there is a combination of journals from different fields, such as operations management (*Journal of Operations Management*, and *Production Planning & Control*), safety and ergonomics (*International Journal of Disaster Resilience in the Built Environment*, and *International Journal of Disaster Risk Reduction*), and healthcare (*International Journal of Pharmaceutical and Healthcare Marketing*, and *Journal of Health Organization and Management*). Finally, 159 authors contributed to the works consolidated in the corpus, and seven of them appeared in two publications each. Figure 4 displays the frequency of publications according to the tier levels of the healthcare supply chain. 76% of the articles studied only one tier level, and the remaining 24% focused on two different tier levels. No work has approached the entire healthcare supply chain. Overall, the variety related to journals, authors and tier levels suggests a scattered distribution of the topic.

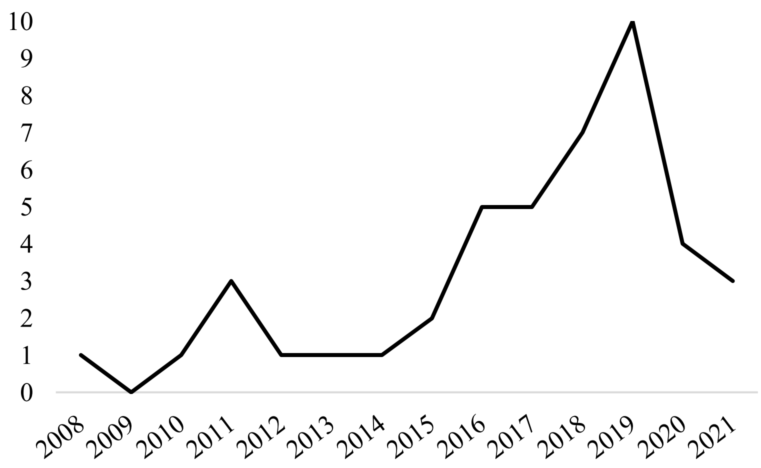

Figure 3 - Frequency of publications per year

Table 2 - Number of publications per journal and author

Journals	Nº of publications	Authors	Nº of publications
International Journal of Lean Six Sigma	3	Almutairi, A.M.	2
Decision Sciences	2	Antony, J.	2
International Journal of Disaster Resilience in the Built Environment	2	Cudney, E.A.	2
International Journal of Disaster Risk Reduction	2	De Carvalho, J.C.	2
International Journal of Pharmaceutical and Healthcare Marketing	2	Dobrzykowski, D.D.	2
Journal of Health Organization and Management	2	Guimaraes, C.M.	2
Journal of Operations Management	2	McFadden, K.L.	2
Production Planning & Control	2	Other 145 authors	1
Others	25		

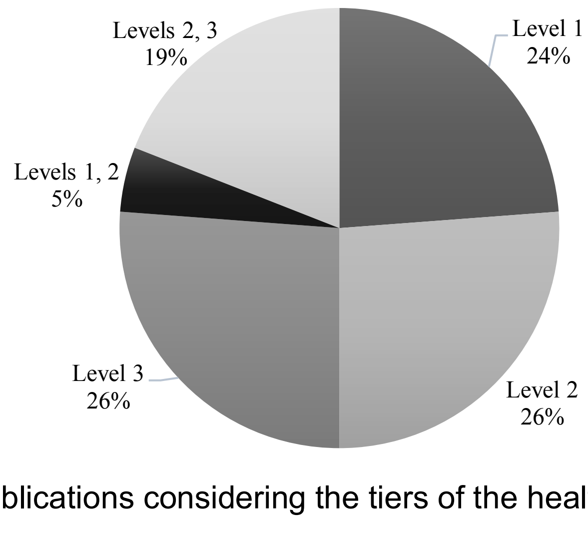

Figure 4 - Publications considering the tiers of the healthcare supply chain

3.4.2 Latent content analysis

Table 3 shows the resilience capabilities that are benefited from the integration of lean practices in the healthcare supply chain. More than half of the articles related lean practices to three resilience capabilities c_3 (efficiency), c_4 (visibility) and c_9 (collaboration). According to Pettit et al. (2013), efficiency defines the ability to produce outputs with minimum resource requirements by means of waste elimination, labor productivity and failure prevention. The adoption of lean practices in the healthcare supply chain is primarily targeted to improve efficiency (Boronat *et al*., 2018) and meet the increasing demand with high-quality services (Waring *et al*., 2010), justifying the high frequency of citation. Visibility is related to knowledge of the status of operating assets and the environment, such as information exchange, error visualization, materials, and people. Lean practices, such as visual management and standardized work, allow more transparent processes facilitating the identification of wastes and abnormalities (Guimarães *et al*., 2013). The collaboration capability refers to working with other entities for mutual benefit. More specifically, it can be translated as the communication between departments, people, and supply chain agents. Lean practices, such as VSM and inventory management, promote a closer collaboration across the supply chain so that common goals are achieved. In opposition, the resilience capability c_{11} (market position) was the least emphasized by the lean practices.

Table 3 - Contributions of lean practices to resilience capabilities in the healthcare supply chain

Lean practices	c_1 - Flexibility	c_2 - Capacity	c_3 – Efficiency	c_4 – Visibility	c_5 - Adaptability	c_6 - Anticipation	c_7 - Recovery	c_8 - Dispersion	c_9 – Collaboration	c_{10} - Organization	c_{11} - Market position	c_{12} – Security/ Safety	c_{13} - Financial strength
p_1 VSM	16, 25, 27, 36, 37, 40, 42	35, 37	9, 10, 11, 12, 13, 15, 16, 21, 24, 25, 26, 27, 36, 37, 39, 40, 42	9, 10, 11, 12, 13, 16, 19, 21, 24, 25, 26, 27, 35, 36, 37, 39, 40	-	40	-	15	2, 12, 13, 16, 19, 24, 25, 26, 27, 36, 37, 40	2, 12, 13	-	9, 12, 12, 13, 24, 27, 37, 40, 42	11, 13, 19
p_2 Visual management	1	30	1, 8, 26, 30, 33, 43	1, 8, 26, 33	1	-	-	33	26, 33	1, 30	-	43	1
p_3 A3	1, 4	3	1, 3, 4	1	1	-	-	4	-	1	-	3	1
p_4 Standardized Work	16, 36, 38	22, 38	8, 9, 10, 11, 12, 13, 16, 26, 36	8, 9, 10, 11, 12, 13, 15, 19, 23, 26, 36, 38	22, 38	38	41		12, 13, 16, 19, 26, 36, 38, 41	12, 13	-	9, 11, 12, 13, 38, 41	13, 19, 23
p_5 Pull System	1, 40	-	1, 10, 26, 29, 40	1, 10, 26, 40	1	40			26, 40	1	-	40	1, 29
p_6 Kanban	1, 27	28, 30, 35	1, 6, 8, 26, 27, 28, 29, 30	1, 6, 8, 26, 27, 28, 35	1	-			26, 27, 28	1, 30	-	27	1, 29
p_7 5S	25, 27, 36	28, 35	9, 11, 25, 26, 27, 28, 29, 36, 43	9, 11, 25, 26, 27, 28, 35, 36	-	-	-		25, 26, 27, 28, 36	-	-	9, 11, 27, 43	29
p_8 Departmental layout	-	-	12, 26, 29, 43	12, 26	-	-	-		12, 26	12	-	12, 43	29
p_9 VMI	25, 40	28	21, 25, 26, 28, 29, 40	21, 25, 26, 28, 40	-	-	-		25, 26, 28, 40	-	-	40	29
p_{10} Inventory management	1, 5, 37, 40	30, 32, 37, 41	1, 3, 13, 21, 24, 26, 28, 30, 32, 33, 37, 40	1, 13, 21, 24, 26, 28, 33, 37, 40	1. 34	14, 40	14, 41	33	13, 14, 24, 26, 28, 32, 33, 37, 40, 41	1, 13, 30	-	3, 13, 24, 34, 37, 40, 41	1, 3, 5, 13
p_{11} Spaghetti diagram	-	-	26, 39	26, 39	-	-	-	-	26	-	-	-	-
p_{12} Just-in-time	7, 27, 40	28, 30	7, 24, 26, 27, 28, 29, 30, 40	24, 26, 27, 28, 40	34	40	-	-	7, 24, 26, 27, 28, 40	30	-	24, 27, 34, 40	29
p_{13} Continuous improvement	20, 25	17	17, 18, 20, 25, 43	19, 25	-	-	-	-	17, 18, 19, 20, 25	-	-	18, 43	17, 18, 19
p_{14} Kaizen	27, 36	35	9, 26, 27, 29, 36	9, 26, 27, 35, 36	-	-	-	-	26, 27, 36	-	-	9, 27	29
p_{15} RFID	27	28	6, 24, 26, 27, 28, 29	6, 24, 26, 27, 28,	-	-	-	-	24, 26, 27, 28	-	-	24, 27	-
p_{16} Autonomation	-	31	8, 13, 15, 24, 26, 29, 31, 33	8, 13, 24, 26, 33, 44	-	-	-	15, 33	13, 24, 26, 31, 33	13, 31	44	13, 24, 31, 44	13, 29
p_{17} Six-sigma	25, 42	-	6, 13, 25, 26, 29, 39, 42	6, 13, 25, 26, 39	-	-	-	-	2, 13, 25, 26,	2, 13	-	13, 42	13
P_{18} Poka-yoke	27, 36	-	27, 29, 36	27, 36	-	-	-	-	27, 36	-	-	27	29
Nº of citations	13	11	34	23	4	3	2	4	23	6	1	17	10

References: 1- Papalexi et al. (2016); 2 - Almutairi et al. (2019); 3 - Haeri et al. (2020); 4 – Haghighi and Torabi (2018); 5- Divsalar et al. (2020); 6 – Dixit et al. (2019); 7 – Tolf et al. (2015); 8 – Ragattieri et al. (2018); 9 - Farrokhi et al. (2015); 10 - Piggott et al. (2011); 11 – Almutairi et al. (2019b); 12 - Narayanamurthy et al. (2018); 13 – Feiber et al. (2019); 14 – Achour et al. (2011); 15 – Tay et al. (2017); 16 – de Vries et al. (2011); 17 – Dobrzykowski and McFadden (2019); 18 – Dobrzykowski et al. (2016); 19 – Shah et al. (2008); 20 – Alshahrani et al. (2018); 21 – Patrone et al. (2020); 22 - Nunes-Vaz et al. (2019); 23 - Guven-Uslu et al. (2014); 24 – Nabelsi and Gagnon (2017); 25 – Ramori et al. (2019); 26 – Borges et al. (2019); 27 – Khorasani et al. (2020); 28 – Volland et al. (2017); 29 – Adebanjo et al. (2016); 30 – Lim et al. (2017); 31 – Kekkonen et al. (2018); 32 – Sabouhi et al. (2018); 33 – Liu et al. (2016); 34 – Duong et al. (2019); 35 – Singh et al. (2016); 36 – Guimarães et al. (2013); 37 - Rahimnia and Moghadasian (2010); 38 – De Lima et al. (2018); 39 – Roberts et al. (2017); 40 - Guimarães et al. (2012); 41 - Friday et al. (2021); 42 - Hundal et al. (2021); 43 – Suresh et al. (2020); 44 - Pandey and Litoriya (2021).

Table 4 displays the frequency of citations of lean practices according to the tier levels of the healthcare supply chain. The lean practice p_1 (VSM) stood out, being mentioned by approximately 45% of the articles. According to Tortorella *et al*. (2017), VSM has been successfully used in different healthcare applications, from small physician clinics to more complex systems such as emergency departments. Due to this versatility, it is reasonable that the VSM appears as the most prominent lean practice. In addition, p_{10} (inventory management) was the second most cited lean practice (36% of the articles), with especial attention to tier levels 1 and 2 of the healthcare supply chain. In opposition, p_{11} (spaghetti diagram) was the least explored, being applied only in tier levels 2 and 3. Regarding the tiers of the healthcare supply chain, tier levels 2 and 3 were the ones in which lean practices have been mostly applied. These levels are closer to the ultimate focus of the healthcare supply chain, which is the patient care (De Vries *et al*., 2011). Hence, the adoption of lean practices at these levels is more likely to provide more significant impacts from the patients' perspective.

Table 4 - Lean Practices according to the tier levels of the healthcare supply chain

	Lean Practices	Level 1	Level 2	Level 3	Nº of citations
p_1	VSM	13, 24	2, 11, 12, 19, 21, 24, 26, 27, 35, 36, 37, 40, 42	9, 10, 11, 15, 16, 19, 24, 25, 26, 27, 39	20
p_2	Visual management	1, 30	26, 33, 43	8, 26, 33	6
p_3	A3	1, 3	-	4	3
p_4	Standardized work	13, 38	11, 12, 19, 26, 36, 41	9, 10, 11, 16, 19, 22, 23, 26	14
p_5	Pull System	1	26, 40	26, 29	4
p_6	Kanban	1, 6, 30	26, 27, 28, 35	8, 10, 26, 27, 28, 29	9
p_7	5S	-	11, 26, 27, 28, 35, 36, 43	9, 11, 25, 26, 27, 28, 29	10
p_8	Departmental layout	-	12, 26, 43	26, 29	4
p_9	VMI	-	21, 26, 28, 40	25, 26, 28, 29	5
p_{10}	Inventory management	1, 3, 5, 13, 24, 30, 32, 34	14, 21, 24, 26, 28, 34, 37, 40, 41	24, 26, 28	16
p_{11}	Spaghetti diagram	-	26	26, 39	2
p_{12}	Just-in-time	24, 30, 34	7, 24, 26, 27, 28, 34, 40	7, 24, 27, 28, 29	9
p_{13}	Continuous improvement	-	17, 18, 19, 20, 43	17, 18, 19, 25	6
p_{14}	Kaizen	-	26, 27, 35, 36	9, 26, 27, 29	6
p_{15}	RFID	6	26, 27, 28	8, 26, 27, 28, 29	6
p_{16}	Autonomation	13, 24, 31, 44	24, 26, 33	8, 15, 24, 26, 29, 33	9
p_{17}	Six-sigma	6, 13	2, 26, 42	25, 26, 29, 39	8
p_{18}	Poka-yoke	-	27, 36	27, 29	3
	Nº of citations	12	22	22	

References: 1- Papalexi et al. (2016); 2 - Almutairi et al. (2019); 3 - Haeri et al. (2020); 4 – Haghighi and Torabi (2018); 5- Divsalar et al. (2020); 6 – Dixit et al. (2019); 7 – Tolf et al. (2015); 8 – Ragattieri et al. (2018); 9 - Farrokhi et al. (2015); 10 - Piggott et al. (2011); 11 – Almutairi et al. (2019b); 12 - Narayanamurthy et al. (2018); 13 – Feiber et al. (2019); 14 – Achour et al. (2011); 15 – Tay et al. (2017); 16 – de Vries et al. (2011); 17 – Dobrzykowski and McFadden (2019); 18 – Dobrzykowski et al. (2016); 19 – Shah et al. (2008); 20 – Alshahrani et al. (2018); 21 – Patrone et al. (2020); 22 - Nunes-Vaz et al. (2019); 23 - Guven-Uslu et al. (2014); 24 – Nabelsi and Gagnon (2017); 25 – Ramori et al. (2019); 26 – Borges et al. (2019); 27 – Khorasani et al. (2020); 28 – Volland et al. (2017); 29 – Adebanjo et al. (2016); 30 – Lim et al. (2017); 31 – Kekkonen et al. (2018); 32 – Sabouhi et al. (2018); 33 – Liu et al. (2016); 34 – Duong et al. (2019); 35 – Singh et al. (2016); 36 – Guimarães et al. (2013); 37 - Rahimnia and Moghadasian (2010); 38 – De Lima et al. (2018) ; 39 – Roberts et al. (2017); 40 - Guimarães et al. (2012); 41 - Friday et al. (2021); 42 - Hundal et al. (2021); 43 – Suresh et al. (2020); 44 - Pandey and Litoriya (2021).

Table 5 shows the frequency of citations of lean practices according to different healthcare value streams. The most frequently studied healthcare value stream in terms of lean implementation was the medical consumables, with 16 citations. Medical consumables represent a large part of the budget of healthcare organizations, encompassing an extremely diversified mix of items, such as needles, syringes, gloves, etc. (Tongzhu *et al.*, 2016). Moreover, its large quantity and variety demand high levels of organization and standardization (Little; Coughlan, 2008), increasing the need for applying lean practices. On the other hand, medical equipment and information were the value streams with the lowest number of citations, suggesting that the application of lean practices in these contexts has been poorly investigated.

Table 5 - Lean practices according to different value streams of healthcare supply chain

	Lean practices	Drugs	Medical Consumables	Patients	Services	Medical Equipment	Workers	Information
p_1	VSM	11, 13, 19, 35	2, 9, 12, 15, 26, 27, 36, 39, 40	10, 12, 13, 15, 16, 25, 42	21, 37	24	-	-
p_2	Visual management	1, 8	26, 33	43	-	-	-	-
p_3	A3	1	-	-	-	-	-	4
p_4	Standardized work	8, 11, 13, 19, 38	9, 12, 26, 36, 41	10, 12, 13, 16, 22, 23	-	-	-	-
p_5	Pull system	1	26, 29, 40	10	-	-	-	-
p_6	Kanban	1, 6, 8, 35	26, 27, 28, 29	-	-	-	-	-
p_7	5S	11, 35	9, 26, 27, 28, 29, 36	25, 43	-	-	-	-
p_8	Departmental layout	-	12, 26, 29	12, 43	-	-	-	-
p_9	VMI	-	26, 28, 29, 40	25	21	-	-	-
p_{10}	Inventory management	1, 13, 32, 34	5, 14, 26, 28, 33, 40, 41	13	21, 37	24	-	-
p_{11}	Spaghetti diagram	-	26, 39	-	-	-	-	-
p_{12}	Just-in-time	34	7, 26, 27, 28, 29, 40	-	-	24	-	-
p_{13}	Continuous improvement	19	20	18, 25. 43	-	-	17	-
p_{14}	Kaizen	35	9, 26, 27, 36	-	-	-	-	-
p_{15}	RFID	6, 8	26, 27, 28, 29	-	-	24	-	-
p_{16}	Autonomation	8, 13, 44	15, 26, 29, 33	13, 15	-	24	31	-
p_{17}	Six-sigma	6, 13	2, 26, 29, 39	13, 25	-	-	-	-
P_{18}	Poka-yoke	-	27, 29, 36	42	-	-	-	-
	Nº of citations	10	16	11	2	1	2	1

References: 1- Papalexi et al. (2016); 2 - Almutairi et al. (2019); 3 - Haeri et al. (2020); 4 – Haghighi and Torabi (2018); 5- Divsalar et al. (2020); 6 – Dixit et al. (2019); 7 – Tolf et al. (2015); 8 – Ragattieri et al. (2018); 9 - Farrokhi et al. (2015); 10 - Piggott et al. (2011); 11 – Almutairi et al. (2019b); 12 - Narayanamurthy et al. (2018); 13 – Feiber et al. (2019); 14 – Achour et al. (2011); 15 – Tay et al. (2017); 16 – de Vries et al. (2011); 17 – Dobrzykowski and McFadden (2019); 18 – Dobrzykowski et al. (2016); 19 – Shah et al. (2008); 20 – Alshahrani et al. (2018); 21 – Patrone et al. (2020); 22 - Nunes-Vaz et al. (2019); 23 - Guven-Uslu et al. (2014); 24 – Nabelsi and Gagnon (2017); 25 – Ramori et al. (2019); 26 – Borges et al. (2019); 27 – Khorasani et al. (2020); 28 – Volland et al. (2017); 29 – Adebanjo et al. (2016); 30 – Lim et al. (2017); 31 – Kekkonen et al. (2018); 32 – Sabouhi et al. (2018); 33 – Liu et al. (2016); 34 – Duong et al. (2019); 35 – Singh et al. (2016); 36 – Guimarães et al. (2013); 37 - Rahimnia and Moghadasian (2010); 38 – De Lima et al. (2018); 39 – Roberts et al. (2017); 40 - Guimarães et al. (2012); 41 - Friday et al. (2021); 42 - Hundal et al. (2021); 43 – Suresh et al. (2020); 44 - Pandey and Litoriya (2021).

3.5 RELEVANCE LEVEL AND FRAMEWORK PROPOSITION

The relevance level derived from the content analysis, and its results are displayed in Table 6. A total of 234 pairwise relationships were assessed, from which 16 (7%) resulted in highly relevant relationships (score = 7, 8, 9), 83 (35%) were of moderate relevance (score = 4, 5, 6), and 146 (58%) were classified as lowly relevant (score = 0, 1, 2, 3).

Highly relevant relationships imply that lean practices are quite likely to support the development of resilience capabilities in the healthcare supply chain. Lean practices p_{10} (inventory management) and p_1 (VSM) stood out with 5 and 4 highly relevant relationships with resilience capabilities, respectively. The relevance levels of both lean practices were high to similar resilience capabilities, such as c_3 (efficiency), c_4 (visibility), c_9 (collaboration), and c_{12} (security/safety). These lean practices are widespread within the healthcare supply chain, and Nabelsi and Gangnon (2017) suggested that their adoption may facilitate the achievement of an increased resilience. Inventory management supports a more efficient healthcare supply chain without negatively affecting the care of patients (Kwon *et al.*, 2016; Volland et al., 2017). In addition, through minimization of waste, VSM promotes a continuous flow of products and information (Tortorella *et al.,* 2016) promoting benefits in the resilience capabilities (De Sanctis *et al.*, 2018). Therefore, one might assume that the implementation of p_{10} and p_1 should be prioritized in situations where the healthcare supply chain is seeking to improve its resilience. In terms of resilience capabilities, c_3 (efficiency) was the one with the highest number of highly relevant pairwise relationships (6) and had no lowly relevant relationship with any lean practice. This suggests that, regardless of the lean practice being adopted, efficiency of the healthcare supply chain may be always affected, complementing indications from Costa and Godinho Filho (2016) and Borges *et al*. (2019).

For relationships of moderate relevance, lean practices and resilience capabilities are assumed to be compatible in certain aspects. In this sense, some adaptations may need to be made for a lean practice successfully support the improvement of a given resilience capability. Such need was more prominent with lean practices p_7 (5S) and p_{15} (RFID), both with 6 moderately relevant relationships with the following capabilities: c_1 (flexibility), c_2 (capacity), c_3 (efficiency), c_4 (visibility), c_{10} (collaboration), and c_{12} (security/safety). In addition, the resilience capability c_1 was found moderately related to 13 lean practices, which suggests that the improvement of flexibility in the healthcare supply chain through lean practices adoption must be carefully conducted. In fact, although supply chain flexibility is one of the implications from the application of lean practices, it has not been the main focus (Agarwal *et al*., 2006; Moyano-Fuentes, 2019).

Relationships with a low relevance indicate that some characteristics of the lean practices and/or resilience capabilities must undergo significant modifications to make the association viable. Thus, these relationships require further analysis to be utilized and the desired results achieved. The lean practice with the highest number of lowly relevant relationships was p_{11} (spaghetti diagram), with 10 relationships. According to Borges *et al.* (2019), this practice is not widely used in the healthcare supply chain despite its benefits, such as identification of inefficient movements and ineffective areas, and layout changes (Senderská *et al.,* 2017). Three resilience capabilities, c_6 (anticipation), c_7 (recovery) and c_{11} (market position), had lowly relevant relationships with all lean practices. Despite the lean practices have the tendency to concern about the future, forecasting and risk management techniques need to be more incorporated into the healthcare supply chain to promote anticipation capability (Konecka, 2010). Also, lean practices could reduce safety margins which can be confused as waste, making the recovery process difficult due to an internal problem, or external problems such as pandemics and natural disasters (Achour *et al.,* 2011) decreasing the influence in the recovery capability. In addition, the capability market position, which is the status of a company or its products in specific markets is not the focus of organizations involving healthcare (Kim *et al.,* 2021). Therefore, to develop these resilience capabilities in the healthcare supply chain, other management approaches besides lean implementation are necessary.

Table 6 - Relevance level of the contribution of lean practices to resilience capabilities in the healthcare supply chain

c	c_1				c_2				c_3				c_4				c_5				c_6			
Lean practice	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*
p_1	2	2	2	6	1	1	1	3	3	3	3	9	3	3	3	9	0	0	0	0	1	1	1	3
p_2	1	1	1	3	1	1	1	3	1	3	2	6	1	3	1	5	1	1	1	3	0	0	0	0
p_3	1	2	1	4	1	1	1	3	1	2	2	5	1	1	1	3	1	1	1	3	0	0	0	0
p_4	1	2	2	5	1	3	2	6	2	3	2	7	3	3	2	8	1	2	1	4	1	1	1	3
p_5	1	2	1	4	0	0	0	0	1	3	2	6	1	3	2	6	1	1	1	3	1	1	1	3
p_6	1	3	1	5	1	2	2	5	2	3	2	7	2	3	2	7	1	1	1	3	0	0	0	0
p_7	1	2	1	4	1	2	1	4	2	2	2	6	2	2	2	6	0	0	0	0	0	0	0	0
p_8	1	0	0	1	0	0	0	0	1	2	1	4	1	2	1	4	0	0	0	0	0	0	0	0
p_9	1	2	1	4	1	2	1	4	1	2	2	5	1	2	2	5	0	0	0	0	1	1	1	3
p_{10}	1	2	2	5	1	3	3	7	3	3	3	9	2	3	3	8	1	1	1	3	1	1	1	3
p_{11}	0	0	0	0	0	0	0	0	1	2	1	4	1	2	1	4	0	0	0	0	0	0	0	0
p_{12}	1	2	1	4	1	3	1	5	2	3	3	8	1	3	1	5	1	2	1	4	1	1	1	3
p_{13}	1	2	1	4	1	2	1	4	1	2	2	5	1	2	1	4	0	0	0	0	0	0	0	0
p_{14}	1	2	1	4	1	1	1	3	1	2	1	4	1	2	1	4	0	0	0	0	0	0	0	0
p_{15}	1	2	1	4	1	2	1	4	1	3	2	6	1	3	2	6	0	0	0	0	0	0	0	0
p_{16}	0	0	0	0	1	1	1	3	2	3	3	8	1	3	2	6	0	0	0	0	0	0	0	0
p_{17}	1	1	1	3	0	0	0	0	1	3	2	6	1	3	2	6	0	0	0	0	0	0	0	0
p_{18}	1	2	1	4	0	0	0	0	1	2	4	3	1	2	1	4	0	0	0	0	0	0	0	0

c	c_7				c_8				c_9				c_{10}				c_{11}				c_{12}				c_{13}			
Lean practice	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*	*i*	*ii*	*iii*	*r*
p_1	0	0	0	0	1	1	1	3	3	3	3	9	1	2	2	5	0	0	0	0	3	3	3	9	1	3	1	5
p_2	0	0	0	0	1	2	1	4	1	2	1	4	1	1	1	3	0	0	0	0	1	1	1	3	1	1	1	3
p_3	0	0	0	0	1	1	1	3	1	0	0	1	1	1	1	3	0	0	0	0	1	1	1	3	1	1	1	3
p_4	1	1	1	3	0	0	0	0	2	3	2	7	1	2	2	5	0	0	0	0	1	3	2	6	1	3	1	5
p_5	0	0	0	0	0	0	0	0	1	2	1	4	1	1	1	3	0	0	0	0	1	1	1	3	1	2	1	4
p_6	0	0	0	0	0	0	0	0	1	2	1	4	1	1	1	3	0	0	0	0	1	2	1	4	1	2	1	4
p_7	0	0	0	0	0	0	0	0	1	2	2	5	0	0	0	0	0	0	0	0	1	2	2	5	1	1	1	3
p_8	0	0	0	0	0	0	0	0	1	2	1	4	1	1	1	3	0	0	0	0	1	2	1	4	1	1	1	3
p_9	0	0	1	1	0	0	0	0	1	2	1	4	0	0	0	0	0	0	0	0	1	1	1	3	1	1	1	3
p_{10}	1	1	1	3	1	2	1	4	2	3	3	8	1	2	2	5	0	0	0	0	2	3	3	8	1	1	2	4
p_{11}	0	0	0	0	0	0	0	0	1	2	1	4	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
p_{12}	0	0	0	0	0	0	0	0	1	3	2	6	1	1	1	3	0	0	0	0	1	2	2	5	1	1	1	3
p_{13}	0	0	0	0	0	0	0	0	1	2	2	5	0	0	0	0	0	0	0	0	1	1	1	3	1	2	2	5
p_{14}	0	0	0	0	0	0	0	0	1	2	1	4	0	0	0	0	0	0	0	0	1	2	1	4	1	1	1	3
p_{15}	0	0	0	0	0	0	0	0	1	3	1	5	0	0	0	0	0	0	0	0	1	3	1	5	0	0	0	0
p_{16}	0	0	0	0	0	2	1	3	1	1	3	5	1	1	2	4	1	1	1	3	1	1	3	5	1	2	1	4
p_{17}	0	0	0	0	0	0	0	0	1	3	1	5	1	2	1	4	0	0	0	0	1	2	1	4	1	1	1	3
p_{18}	0	0	0	0	0	0	0	0	1	2	1	4	0	0	0	0	0	0	0	0	1	2	1	4	1	1	1	3

Note: Gray scale indicates the relevance level of the pairwise relationship

Figure 5 displays the proposed framework related to the relationships between lean practices and resilience capabilities according to the healthcare value streams at each tier level of the healthcare supply chain. For developing resilience capabilities of healthcare supply chain from tier level 1, the most important lean practices appear to be 'inventory management', 'continuous improvement' and 'kanban'. These lean practices are likely to influence the improvement of the 'visibility', 'efficiency' and 'security/safety'. Further, the 'drugs' value stream seem to be the most benefited one, especially due to the presence of reports involving pharmaceutical companies (e.g., Papalexi *et al*., 2016). At tier level 2, the lean practices that stood out were 'VSM', 'inventory management', 'JIT' and '5S'. The adoption of these practices may be highly important for developing the resilience capabilities 'efficiency', 'visibility' and 'collaboration', with emphasis for the 'medical consumables' value stream. Finally, at tier level 3, 'VSM', 'standardized work' and '5S' appeared to be particularly relevant for enhancing the resilience capability of the 'patient' value stream, positively affecting the 'efficiency', 'visibility' and 'collaboration'.

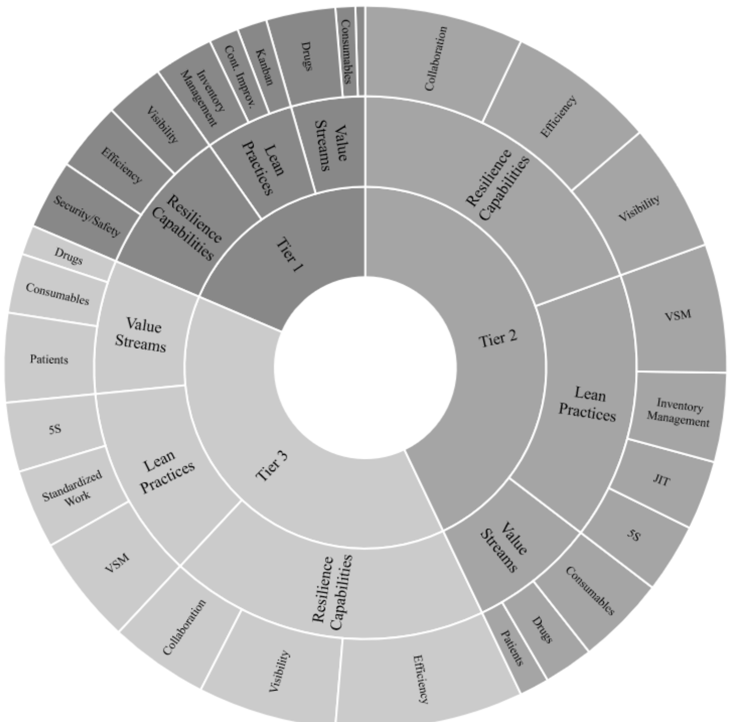

Figure 5 – Framework of main lean practices, resilience capabilities and value streams at each tier level of the healthcare supply chain

3.6 RESEARCH DIRECTIONS

One of the main outcomes of a scoping review is the proposition of future research directions (Brown, 2019). Through the detailed analysis of the literature, three main research directions were raised: (*i*) empirical validation of the contribution of lean practices to resilience capabilities in the healthcare supply chain; (*ii*) systemic implementation of lean practices across tier levels of the healthcare supply chain; (*iii*) complementary approaches to lean implementation towards a more resilient healthcare supply chain.

Empirical validation of the contribution of lean practices to resilience capabilities in the healthcare supply chain

The proposed framework conceptually indicated the relevance level of the relationships between lean practices and resilience capabilities in the healthcare supply chain, serving as a theoretical basis for researchers and managers involved in the healthcare supply chain. However, these relationships still need to be empirically validated. The empirical validation is fundamental to understand convergences and divergences from theory to practice. Thus, future research could encompass the utilization of empirical methods, such as surveys, semi-structured interviews, and case studies, to verify the intensity of those relationships at different tier levels of the healthcare supply chain. This should be performed across various healthcare value streams so that it becomes possible the triangulation of findings and the proposition of more generalizable indications. These research directions would also provide more robust evidence of synergies between lean practices and resilience capabilities in the healthcare supply chain, allowing for complementary insights and implementation guidelines.

Systemic implementation of lean practices across tier levels of the healthcare supply chain

The corpus of articles addressed the application of lean practices in just one or at most two tiers of the healthcare supply chain. Studies that investigate the lean implementation simultaneously across all tiers to enhance the overall resilience of the healthcare supply chain were not found. The tiers of the healthcare supply chain are complex and interdependent entities that must maintain the supply of materials, information, and equipment to avoid disruptive events (Markman; Krause 2016). Mandal *et al*. (2018) indicated the lack of studies on the integration of the healthcare supply chain, and found that the integration between tier levels had a positive influence on operational performance. In addition, Ramanathan and Gunasekaran (2014) argued that collaborative activities between the tiers are important for effective supply chain management. Hence, further research is necessary to explore the integrated application of lean practices in the entire healthcare supply chain, so that the development of resilience capabilities can be assessed from a more holistic perspective.

Complementary approaches to lean implementation towards a more resilient healthcare supply chain

Our study solely focused on the lean implementation as a means to enhance resilience in the healthcare supply chain. However, there may be other management approaches that could either complement (or even substitute) lean practices, such as the digitalization of healthcare processes and treatments (Tortorella *et al.,* 2021). In this sense, understanding how the concurrent implementation of lean practices and additional management approaches could impact the resilience of the healthcare supply chain is still underexplored. Such complementary research could also shed light on the development of some resilience capabilities of the healthcare supply chain (e.g., anticipation, recovery, and market position) whose relationships with lean practices were considered as lowly relevant in our conceptual framework.

3.7 CONCLUSIONS

The objective of this work was to identify the relationship between lean practices and resilience capabilities in the healthcare supply chain. To this end, a scoping review was carried out in five databases, resulting in the analysis of 44 publications. Such analysis allowed the verification of trends and volume of studies on this topic. Further, the descriptive numerical and thematic analyses enabled the proposition of a conceptual framework, relating the adoption of lean practices to the development of resilience capabilities according to the tiers of the healthcare supply chain in different value streams. To the best of our knowledge, there is no similar study in the literature. In practical terms, the understanding of these relationships provides healthcare managers arguments to prioritize the application of lean practices to improve desired resilience capabilities in the entire healthcare supply chain.

Some limitations of this study deserve to be highlighted. Regarding the search method, five databases widely addressed in the literature were used. However, it is worth noting the existence of relevant works that may not be included in these databases. In addition, the concept of resilience is still vague in the literature, with different perspectives. The propositions from Pettit *et al.* (2013) were followed, but future studies could encompass complementary propositions so that a broader view of resilience in the healthcare supply chain is established. Finally, the content analysis involved only two axes: healthcare value streams and supply chain tier levels. Therefore, other perspectives could be added, raising new insights from the body of literature and contributing to those already discussed here.

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4 LEAN AND RESILIENCE IN HEALTHCARE SUPPLY CHAIN – A MEDIATION ANALYSIS

Abstract: This article aims at examining the mediating role of resilience development on the association between lean principles adoption and operational performance in healthcare supply chain. This study carried out a survey of 123 Brazilian workers from healthcare supply chain. Two hypotheses were tested: H1 - Lean principles adoption positively impacts the resilience development in healthcare supply chain and H2 - The resilience development positively mediates the effect of lean principles adoption on operational performance in healthcare supply chain. It was carried out a set of Ordinary Least Square (OLS) hierarchical linear regression models to test the hypotheses. The results showed that both hypotheses were supported. Regarding the theoretical contributions, the study brings empirical evidence involving these relationships since these verifications are scarce in the literature. Regarding practical contributions, the results of this research can help managers to establish clearer expectations regarding the lean principles adoption into the healthcare supply chain in an environment with many disruptions. Also, understanding how resilience behaves in the relationship between lean principles adoption and operational performance can contribute to a leaner and more resilient supply chain in healthcare.

Keywords: Resilience; Lean; Healthcare Supply Chain; Operational Performance

4.1 INTRODUCTION

In an interconnected world, organizations and their supply chains are continuously challenged by pressure for more efficient processes (Habibi *et al.,* 2021). In this way, a lean supply chain implementation can be an important key to improving operational performance (Arif-Uz-Zaman; Ahsan, 2014). The general goal of lean supply chain is removing the waste derived from non-added-value activities including waiting, overproduction, motion, transportation, excessive processing, inventory, and underutilization (Khorasani *et al*., 2020). However, these removes can make it more difficult for the system to immediately

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recover against unexpected disruptions that lead to an interruption throughout the supply chain (Ruiz-Benítez *et al*., 2018).

Disruptions can manifest in numerous ways, from operational delays and quality issues in the production process to equipment failures, accidents, pandemics, and natural disasters (Habibi *et al*., 2021). More specifically, healthcare organizations and their suppliers, partners, and stakeholders must develop countermeasures that can protect their operations in the occurrence of a disruption, creating a resilient supply chain (Mandal, 2017). Ponomarov and Holcomb (2009) define a resilient supply chain as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions and recover from them by maintaining continuity of operations at desired levels of connectedness and control over structure and function".

To increase resilience in healthcare supply chain it is important increasing redundancy across the entire supply chain, which assumes keeping some additional resources in reserve to be used in case of disruption (Maslaric *et al.,* 2013). However, the increase in resources can go against lean's concept of reducing waste, creating a conflict between lean and resilience. On the other hand, lean and resilience can work mutually to improve operational performance in healthcare supply chain (Rosso; Saurin, 2018). Therefore, empirical evidences linking lean, resilience and operational performance are needed to better understand synergies and divergences and for improvements across the entire healthcare supply chain.

There are some studies regarding lean or resilience and operational performance in supply chain in the literature. For example, The literature review of D'Andreamatteo *et al.* (2015) demonstrates the positive influence of lean on healthcare performance, when positive outcomes were observed related to productivity and cost efficiency, clinical quality, patient and staff safety and financial result. Adebanjo *et al.* (2016) investigate the perceptions of experts on the healthcare supply chain about the prioritization of healthcare performance measures and their relationship with lean practices. Lotfi *et al*. (2018) highlights the lack of empirical studies involving the relationship between resilience and operational performance and brings a study involving the relationship between lean and performance resilience in the automotive industry. Birkie *et al.* (2017) investigates the relationship between resilience and performance involving the concept of supply chain complexity. However, no studies were found involving lean, resilience and operational performance together in the context of the healthcare supply chain, especially on how resilience influences the association between lean and operational performance. Thus, the following research question is formulated:

(*i*) How does resilience development influence the association between lean principles adoption and operational performance in healthcare supply chain?

Therefore, this article aims at examining the mediating role of resilience development on the association between lean principles adoption and operational performance in healthcare supply chain. In this sense, a survey was carried out involving 123 respondents of Brazilian healthcare supply chain workers. From this study, there are theoretical and practical contributions. The theoretical contribution of this study is to provide evidence that empirically verifies lean principles adoption impacts on resilience development, and evidence that empirically verifies the mediating role of resilience development between lean principles adoption and operational performance in healthcare supply chain, since these analysis was not found in the literature. Regarding practical contributions, the results of this research can help managers to establish clearer expectations regarding the lean principles adoption into the healthcare supply chain in an environment with many disruptions. Understanding how resilience behaves in the relationship between lean and operational performance can contribute to a leaner and more resilient supply chain.

4.2 BACKGROUND AND HYPOTHESES FORMULATION

4.2.1 Lean principles

Although lean was initially developed to improve automotive production, lean principles applications reach well beyond the production of goods to service and healthcare delivery (De Souza, 2009). The five lean principles are: (*i*) identify value from the customers perspective; (*ii*) identify the value stream for each material or service and the steps and processes considered as waste; (*iii*) create flow continuously and standardize processes; (*iv*) introduce ‘pull’ between all steps where continuous flow is not possible and (*v*) manage towards perfection (Womack *et al.,* 1990).

Regarding the first lean principle, some studies on the healthcare supply chain can be highlighted. For example, Efe and Efe (2016) analyze the value perceived by patients to apply lean principles in the emergency department. In addition, McAdam *et al*. (2021) show that lean is overly focused on healthcare providers rather than patients, thus a patient-focused value stream framework is proposed. Regarding the second lean principle, Tortorella *et al*. (2017) demonstrate the benefits of analyzing healthcare processes using value stream mapping as reduction of wastes, production lead times and inventory levels. Also, Henrique *et al*. (2016) present a value stream mapping approach for healthcare environments that was able to identify some operational bottlenecks that interfere in the patient’s treatment that could not be identified by other mapping models studied.

Regarding the third lean principle, Doğan and Unutulmaz (2016) simulate scenarios to promote the continuous flow of patients in a hospital. Further, Wang *et al.* (2015) also use simulation on solving a combined hospital emergency department layout design and staff attribution problem to promote continuous flow. Regarding the fourth lean principle, Persona et al. (2008) provide an empirical study of efficient management results obtained by the use of the Kanban to promote a pull system. Moreover, Lanza-León *et al.* (2021) review the literature addressing the use of Kanban, a tool to pull system and show the advantages and disadvantages caused by the implementation of this system in healthcare supply chain. Concerning the last lean principle, Henrique *et al*. (2021) proposes a framework to assess sustaining continuous improvement in lean healthcare. Additionally, Bortolotti *et al.* (2008) identify the most influential determinants of healthcare employees’ problem-solving capabilities and attitudes towards kaizen initiatives to promote continuous improvement.

4.2.2 Lean and resilient supply chain

Mandal (2017) affirms that resilience capabilities must be developed by healthcare supply chain to safeguard their operations in the event of disruptions. Pettit *et al.* (2010) define supply chain resilience capabilities as: “attributes that enable an enterprise to anticipate and overcome disruptions." The main supply chain resilience capabilities are: flexibility, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security and financial strength.

There are some studies addressing resilience development in the healthcare supply chain. For example, Mandal (2017) explore the influence of dimensions of organizational culture on healthcare supply chain resilience. Similarly, Rehman and Ali (2021) aims to prioritize resilience strategies for healthcare supply chains while considering the risks that most severe, probable to occur and have the lengthiest periods of recovery. Also, Senna *et al*. (2021) propose a framework for analyzing the relationships between the antecedent factors, mediators, and consequents of healthcare supply chain resilience.

Some studies address resilience linked with lean concept in supply chains. For example, De Sanctis *et al.* (2018) propose a methodology that allows quantification and prediction of impacts of unexpected and expected events in organizations that adopt lean. In addition, Azadeh *et al.* (2017) conduct performance assessment of resilience and lean production integration by a study case in a pipe manufacturer. However, empirical studies addressing the impact of lean principles adoption in the resilience development specifically on the healthcare supply chain are lacking. This gap can be evidenced by the literature review of Ellis *et al*. (2019) where less than 2% of the articles of the articles that study about resilience in healthcare supply chain, address the use of lean.

Therefore, the relationship between lean and resilience in the healthcare supply chain, whether negative or positive, is still not clear from the existing literature (Ruiz-Benítez *et al*., 2018). On the one hand, lean adoption can motivate the improvement of resilience development, suggesting a synergistic relationship between them as presented in some works. For example, Rosso and Saurin (2018) proposes, based on design science research, that from the elimination of waste through the adoption of lean, it is possible to reallocate resources to improve resilience. Also, Soliman *et al.* (2018) through their study suggests that the lean adoption increase resilience development. On the other hand, although lean principles have served as an improvement tool for service systems, organization have a tendency to find low-cost solutions and become more vulnerable (Azadeh *et al.,* 2017). The increased vulnerability caused by the application of lean practices can negatively impact the ability of supply chains to adapt to disruptive events, affecting resilience development (Habib Rad *et al.,* 2021). Based in these arguments, the following hypothesis has been formulated to be tested:

H_1: Lean principles adoption positively impacts the resilience development in healthcare supply chain.

From another perspective, the literature review of Habibi Rad *et al*. (2021) shows that a few studies have examined the impact of lean and resilience paradigms on operational performance and suggest an approach to this topic for future studies. On the one hand, some works show the positive relationship between lean, resilience and operational performance (Rui-Benítez *et al*., 2018). On the other hand, the imbalance between lean principles adoption into the development of resilience can result in adverse effects on operational performance (Azadeh *et al*., 2017). Consequently, misalignment with existing resilience capabilities can weaken successful adoption of lean principles, discrediting their anticipated benefits. Thus, to examine the role of resilience development with regard to the association between lean principles adoption and operational performance improvement, the following hypothesis has been formulated:

H_2: The resilience development positively mediates the effect of lean principles adoption on operational performance in healthcare supply chain.

Based on the propositions derived from the formulation of the hypotheses and literature review, a conceptual framework is presented in Figure 6 to investigate the direct effect of lean principles adoption on resilience development (hypothesis H1) and the mediating effect of resilience on the relationship between lean principles adoption and operational performance (hypothesis H2). Lean principles adoption construct is the independent variable that are suggested to improve operational performance, while resilience development construct is also expected to improve operational performance and positively mediate the impact of lean principles adoption on operational performance. Company size and tier level are used as control variables. The subsequent sections report the empirical results of the testing of this theoretical model.

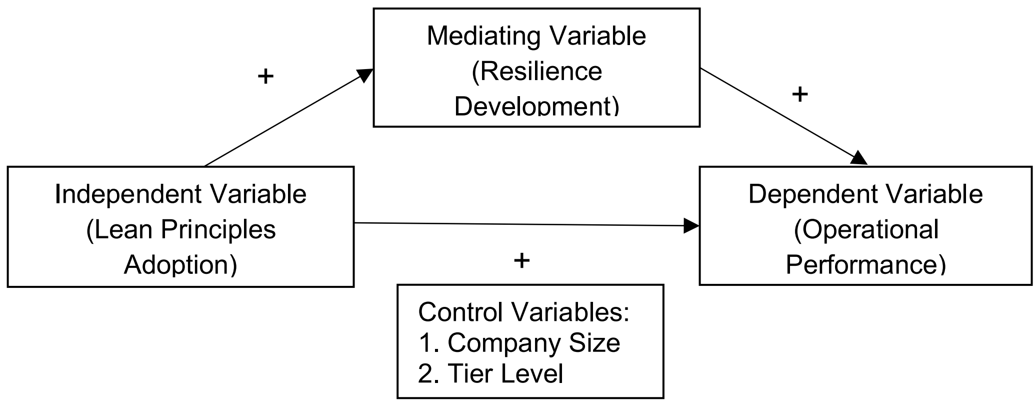

Figure 6 - Theoretical Model

4.3 METHOD

4.3.1 Sample selection, instrument development and data collection

The method chosen for this study was a survey. For the selection of the sample, a business social network was used in order to identify Brazilian professionals who work in the healthcare supply chain and have experience with the lean adoption in their respective organizations. Due to the purpose of the present research, specific criteria were determined to select respondents for the study. A non-random approach for respondents' selection, which is a common practice in survey-based studies was used (Tortorella *et al*., 2018). Also, a presentation brief detailing the purpose of the study was sent to the respondents and it was indicated in the invitation that the participation was voluntary and anonymous. About 600 leaders of a diverse range of Brazilian health manufacturing companies, distributors and providers, and hospitals and medical clinics received the questionnaire. One month after sending the questionnaire, 123 responses were collected. Table 7 shows the sample composition of the respondents.

A pre-test of the questionnaire was applied to four invited people that work in the healthcare sector. The respondents filled out the questionnaire, recorded the time for completion and provided feedback about possible mistakes. Finally, some adjustments were made to improve the questionnaire.

Table 7 - Sample Composition

Category	Description	Quantity	%
Tier Level	1	34	27.6
	2	30	24.4
	3	59	48.0
Company Size	Small (<100 employees)	28	22.8
	Medium (100-500 employees)	21	17.1
	Large (>500 employees)	74	60.1
Respondents' experience with LP	< 2 years	33	26.8
	> 2 years	90	73.2
Respondents' job title	Supervisor or Coordinator	31	25.2
	Manager or Director	92	74.8

The questionnaire comprised four main parts (see the Appendix). The first section was formed about information of the respondents and their respective organizations. The second section was composed by five questions related to the five lean principles implementation, where a 5-point Likert scale (1 referred to 'not used' and 5 denoted 'fully adopted') was used. The third section was composed by 13 questions about resilience capabilities based on work of Pettit *et al.* (2013). Also, a 5-point Likert scale was used (1 referred to 'poor improvements' and 5 denoted 'good improvements'). Finally, in the fourth section, respondents were asked to indicate in a 5-point Likert scale from (1 referred to 'worsened significantly' and 5 referred to 'improved significantly') the observed variation during the last three years of the following operational performance indicators: Quality, Productivity, Costs and Customer/patient satisfaction).

Furthermore, two contextual characteristics were added as control variables: tier level and company size. Regarding the tier level variable, the healthcare supply chain can be divided in three main tier levels as evidenced by Papalexi *et al*. (2020): 1- Manufacturers, 2- Providers and Distributors and 3- Hospital or Medial Clinics. Regarding the company size variable, it was considered three categories for this variable: large-sized organizations (≥ 500 employees), medium-sized organizations (100 - 500 employees) and small organizations (< 100 employees).

4.3.2 Common method variance

Common method variance (CMV) occurs when responses of a questionnaire systematically vary because of the use of a common scaling approach on measures derived from a single data source (Fuller *et al.,* 2016). To avoid CMV in the dataset of the present study, few countermeasures were applied as recommended by Podsakoff and Organ (1986). With regards to questionnaire format, dependent variables were located first of independent variables. Regarding respondent bias, an explicit statement was inserted in the message to respondents, informing that there were no right answers for the questions and the answers were anonymous. Additionally, Harman's One-Factor Test was used. The test indicates problematic CMV if, from an exploratory factor analysis with all the variables of the study, it produces eigenvalues suggesting that the first factor is responsible for more than 50% of the variance between the variables (Podsakoff; Organ, 1986). The variables were tested and the first factor accounted 36.49% of the variance, therefore no problem related to this topic was identified.

4.3.3 Measures, construct validity and reliability

For analysis of the three constructs (lean principles adoption, resilience development and operational performance), the software SPSS® was used. For lean principles adoption items it was performed an Exploratory Factor Analysis (EFA) via Principal Component Analysis (PCA) using varimax rotation to extract orthogonal components (Table 8). The loading factors were considered adequate as they exceeded the minimum value to be a useful representative of the factor which is 0.3 (Pasquali, 2010), therefore the five items loaded into a single factor. The eigenvalue resulted in 2.915 and representing approximately 58.29% of variation. Analogously, for resilience development items it was carried out another PCA with varimax rotation. This analysis resulted in one single factor with an eigenvalue of 6.720, and percent of variance explained of 51.69% (Table 9). Finally, it was performed over again the PCA for operational performance items. This analysis resulted also in one single factor with an eigenvalue of 2.546, and percent of variance explained of 63.66% (see Table 10).

Two measures were used to evaluate the degree of internal consistency and reliability of all three constructs: Cronbach's alpha and Composite Reliability. Cronbach Alpha values ranged from 0.805 to 0.922, whilst Composite reliability values ranged from 0.875 to 0.933, both meeting recommended benchmarked thresholds of 0.700 (Hair *et al.*, 2019). The metric used for evaluating a construct's convergent validity is the average variance extracted (AVE) for all items on each construct. To assess discriminant validity, it was checked whether the AVE of each construct was larger than the squared correlation coefficients involving the constructs (see Table 11). Since, all AVE values accomplished such criterion, discriminant validity was confirmed for the constructs.

Table 8 - Principal Component Analysis to Lean principles adoption

Lean principles	Mean	SD	Communalities	Factor loadings
Identify value	4.048	1.122	0.570	0.753
Map the value stream	3.479	1.250	0.522	0.729
Create flow	4.228	0.913	0.643	0.797
Establish pull system	4.048	1.134	0.544	0.744
Establish continuous improvement	4.374	0.824	0.636	0.798
Extraction sum of squared loadings (total)				2.915
Percent of variance explained				58.290%
Cronbach α				0.809
Bartlett's test of sphericity				195.581
Kaiser-Meyer-Olkin measure of sampling adequacy				0.823
AVE				0.731
Composite reliability (CR)				0.879

Extraction method: principal component analysis.

Table 9 - Principal Component Analysis to Resilience Development

Resilience development	Mean	SD	Communalities	Factor loadings
Capability to quickly change inputs or the mode of receiving inputs (flexibility)	4.024	0.741	0.521	0.722
Capability of assets to enable sustained service levels (capacity)	4.167	0.682	0.491	0.701
Capability to know the status of the processes (visibility)	4.366	0.656	0.496	0.704
Capability to produce results with minimal resource (efficiency)	4.341	0.638	0.505	0.711
Capability to modify operations in response to challenges (adaptability)	3.967	0.768	0.522	0.723
Capability to discern potential future events or situations (anticipation)	4.001	0.741	0.491	0.700
Capability to return to normal operating state quickly (recovery)	3.724	0.739	0.509	0.713
Capability of broad distribution or decentralization of assets (dispersion)	3.959	0.772	0.573	0.757
Capability to work effectively with other entities for mutual benefit (collaboration)	3.968	0.712	0.486	0.697
Capability to use human resource structures (organization)	4.130	0.689	0.502	0.708
Capability of reputation of the organization in the market (market position)	3.919	0.785	0.581	0.762
Capability to defend against deliberate intrusion or attack (security)	4.154	0.725	0.494	0.703
Capability to absorb fluctuations in cash flow (financial strength)	4.065	0.698	0.550	0.741
Extraction sum of squared loadings (total)				6.720
Percent of variance explained				51.69%
Cronbach α				0.922
Bartlett's test of sphericity				836.876
Kaiser-Meyer-Olkin measure of sampling adequacy				0.896
AVE				0.517
Composite reliability (CR)				0.933

Extraction method: principal component analysis.

Table 10 - Principal Component Analysis to Operational Performance

Operational performance	Mean	SD	Communalities	Factor loadings
Quality	4.276	0.631	0.693	0.833
Productivity	4.374	0.592	0.726	0.852
Costs	4.089	0.701	0.568	0.754
Patient/Customer Satisfaction	4.081	0.609	0.559	0.748
Extraction sum of squared loadings (total)				2.546
Percent of variance explained				63.66%
Cronbach α				0.805
Bartlett's test of sphericity				162.62
Kaiser-Meyer-Olkin measure of sampling adequacy				0.766
AVE				0.637
Composite reliability (CR)				0.875

Extraction method: principal component analysis.

Table 11 - Correlation of analyzed variable

Variables	1	2	3	4	5
1 - Tier level	-				
2 - Company size	0.077	-			
3 - Operational performance	-0.229**	-0.021	-		
4 – Resilience development	0.061	0.112	0.570*	-	
5 - Lean principles	-0.169	0.237*	0.407*	0.418*	-

Note: * Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).

4.4 DATA ANALYSIS

For data analysis, a set of Ordinary Least Squares (OLS) hierarchical linear regression models was carried out to test the theoretical model illustrated in Figure 6. Consequently, three models were examined. Model 1: Regression with resilience development (dependent variable) and lean principles adoption (independent variable); Model 2: Regression with operational performance (dependent variable) and lean principles adoption (independent variable) and Model 3: Operational performance was regressed on both independent (lean principles adoption) and mediating (resilience development) variable. The control variables were regressed in all the three models.

According to Baron and Kenny (1986) for a variable to be considered a mediating variable it must satisfy some conditions: (*i*) the independent variable must significantly predict the dependent variable; (*ii*) the dependent variable must significantly predict the mediating variable; (*iii*) the mediating variable must significantly predict the dependent variable and (iv) the independent variable must predict the dependent variable more weakly after insertion of the mediating variable (Preacher; Hayes, 2004). Therefore, all these conditions were tested to observe if there is the mediation that was hypothesized.

The multicollinearity on the estimated coefficients was verified by the calculation of the variance inflation factors (VIF) for all variables, which were all below five. In this way, multicollinearity between variables was disregarded (Mansfield; Helmes, 1982). Also, assumptions related to normality, linearity and homoscedasticity were verified between independent, mediating and dependent variable (Hair et al., 2010). Residuals were analyzed to confirm normality of the error term distribution. Further, linearity was checked with plots of partial regression for each model. Finally, homoscedasticity was assessed by plotting standardized residuals against predicted value and examining visually. Overall, all tests confirmed the requirements for an OLS regression analysis.

4.5 RESULTS AND DISCUSSION

Results in Table 12 display the standardized coefficients of regression models. Model 1 showed that resilience development construct was significantly and positively associated with the lean principles adoption construct (p-value < 0.01), with an adjusted R^2 of 0.170. The results suggest that when healthcare supply chain adopt lean principles, their resilience development are also likely to be improved, supporting hypothesis H1.

These findings are consistent with indications from Ruiz-Benítez *et al.* (2018), which findings highlight that lean and resilience are closely connected. Ruiz-Benítez *et al*. (2018) assert that lean principles implementation may clearly lead to resilient developments by being drivers of the last ones. The lean adoption can result in a supply chain more vulnerable to disruptions (Govindan *et al*., 2015). Therefore, companies that implement lean also need the implementation of resilient capabilities to overcome the increasing vulnerability of their supply chain and to achieve an adequate supply chain performance (Ruiz-Benítez *et al.,* 2018). Also, the findings are consonant with the proposition of Rosso and Saurin (2018) that 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 (Hundal *et al.,* 2021).

Results for Model 2 indicated that the adoption of lean principles adoption are indeed positively associated with Operational Performance (β=0.474; p-value

< 0.05), explaining 24.6% of its variation (F-value= 14.05; p-value < 0.05). However, when resilience development construct is included in the regression analysis (Model 3), results displayed a significant increase in the ability to predict Operational Performance variation (change in adjusted R^2=0.161; p-value < 0.05). Such fact denotes that, although the lean principles adoption has a positive direct effect (Model 2), the inclusion of their indirect effects through the development of resilience development (mediating effect) significantly improves the level of Operational Performance (Model 3). Therefore, these findings support hypothesis H2. The summary of the results of the hypotheses is showed in Table 7.

The findings of Model 2 are consistent with indications of Zhang (2021) that shows empirically that lean adoption has a positive impact on operational performance of hospitals. More specifically, Yeh *et al.* (2011) show the positive impact of lean on costs performance and Alkhaldi *et al.* (2019) show the positive impact of lean in the quality performance of the healthcare supply chain. In the same way, Panwar *et al.* (2018) and Sharma *et al.* (2015) provide empirical evidence of this relationship in other sectors such as the automotive sector. From Model 3, it can be inferred that the indirect effect of lean principles adoption through resilience development has a prevailing effect on operational performance. The findings of Model 3 are related to the work of Birkie (2016) that shows that there is a positive synergy between lean and resilience in facing disruptive events. In other words, their combined effect is complementary and better than that of each one individually to improve the operational performance. Therefore, for a company with a high degree of lean adoption, its resilience is likely to be high as well (Birkie, 2016). Therefore, if lean principles adoption is properly adopted in a company that extensively reinforces resilience capabilities and whose objectives tend to converge to these lean principles, operational performance results are likely to present larger improvement leaps.

Regarding the control variables, company size had no significant effect on any of the models. That is, there is no significant relationship between company size and resilience, and company size and operational performance. In turn, the Tier Level control variable had a significant but negative effect on operational performance. This means that the further away from the end customer in the supply chain (upstream) the operational performance improvement score is greater. The closer you get to the end customer, the operational performance improvement score is lower. Table 13 summarizes the hypotheses and their results.

Table 12 - Standardized β coefficients for hierarchical regression analysis

Variables	Resilience	Operational Performance	
	Model 1	Model 2	Model 3
Tier Level	0.005	-0.164*	-0.166*
Company Size	0.008	-0.121	-0.125
Resilience			0.446*
Lean	0.435*	0.474*	0.280*
F-value	9.180*	14.058*	21.517*
R^2	0.191	0.265	0.426
Adjusted R^2	0.170	0.246	0.406
Change in Adjusted R^2			0.161*

Note: *Coefficient significant at 5%

Table 13 - Hypothesis Results

Hypothesis	**Decision**
H1 Lean principles → Resilience development	Supported
H2 Lean principles → Resilience development→ Operational performance	Supported

4.6 CONCLUSIONS

This study carried out a survey of 123 Brazilian workers from healthcare supply chain to investigate the mediating role of resilience development on the relationship between lean principles adoption and operational performance improvement. Two hypotheses were tested and supported by the results.

The contributions of this research are twofold. First, in theoretical terms, the study verified empirically that lean principles adoption impacts positively on resilience development in healthcare supply chain, since this relationship was questionable and some authors considered a negative relationship between them. Moreover, the literature mostly addresses studies involving lean and resilience in other sectors, so this study extends this approach to the healthcare context. Furthermore, similar studies involving mediation analysis of this topic were not found even in other supply chain sector. So, this study provides the first evidence in this approach, verifying empirically that resilience development mediates the association between lean principles adoption and operational performance.

Regarding practical contributions, the results of this research can help managers to establish clearer expectations regarding the lean principles adoption into the healthcare supply chain in an environment with many disruptions. The study provides more security for supply chain managers to adopt lean principles knowing that it positively impacts resilience and operational performance. Moreover, lean and resilience are often treated individually and often as opposing forces. Therefore, this study shows that these two paradigms can be developed mutually and with a common goals, as the improvement of operational performance.

Finally, a few limitations of this study are worth to be highlighted. Regarding the sample, the fact that respondents were workers from Brazilian healthcare supply chain restricts the generalization of the findings to other countries. Also, the number of respondents could be higher to have more representation. Furthermore, the concept of resilience in the supply chain is still much dispersed, and other approaches could be used as well as the concept of lean, which could generate different results. Similarly, other operational performance indicators could be used.

Some suggestions for future studies are highlighted. The first suggestion is to promote a case study in a healthcare supply chain organization that has lean principles adoption and study how resilience development behaved during a highly disruptive event as Covid-19 pandemic. From the case study, it would be possible to understand nuances that were not collected only with the survey. A second suggestion is to analyze other constructs such as agile and green that are very important in the healthcare supply chain context (Ahmed *et al*., 2020; Klerk; Singh, 2021) to establish relationships and mediations along with lean, resilience and operational performance in healthcare supply chain.

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APPENDIX – APPLIED QUESTIONNAIRE

1) At what tier level of the healthcare supply chain do you work?
( ) Manufacturing/Producers of healthcare supplies
( ) Distributor/Vendors
( ) Hospitals/Medical Clinics

2) What is your job title in your organization? ___________

3) How long have you been in this role within the organization?
( ) less than 2 years
( ) more than years

4) In which department do you work? ___________

5) How many employees does your organization have?
( ) up to 99 workers
( ) between 100-499 workers
( ) more than 500 workers

6) How many years of experience do you have with lean adoption?
( ) less than 2 years
( ) more than years

7) Please, indicate the adoption level in your company of each of lean principles below:
* Scale: from 1 (not used) to 5 (fully adopted)
a) ( ) We develop detailed information regarding the customer's requirements and expectations.
b) ( ) We identify wastes or non-value added activities in the implemented processes.
c) ( ) The flow of steps throughout a procedure is smooth with the least interruptions possible.
d) ( ) Most of the steps of processes are started as soon as they are requested by the customer.
e) ( ) Continuous effort involves employees from the highest level management to the lowest production level to implement the Lean concept in our work.

8) Lean principles were implemented in which value streams? ________

9) Please, indicate the improvement level in your company of each resilience capability:
* Scale: from 1 (poor improvements) to 5 (good improvements)
a) Capability to quickly change inputs or the mode of receiving inputs (flexibility) ( )
b) Capability of assets to enable sustained service levels (capacity) ( )
c) Capability to know the status of the processes (visibility) ( )
d) Capability to produce results with minimal resource (efficiency) ( )
e) Capability to modify operations in response to challenges (adaptability) ( )
f) Capability to discern potential future events or situations (anticipation) ( )
g) Capability to return to normal operating state quickly (recovery) ( )
h) Capability of broad distribution or decentralization of assets (dispersion) ( )
i) Capability to work effectively with other entities for mutual benefit (collaboration) ( )
j) Capability to use human resource structures (organization) ( )
k) Capability of reputation of the organization in the market (market position) ( )
l) Capability to defend against deliberate intrusion or attack (security) ( )
m) Capability to absorb fluctuations in cash flow (financial strength) ( )

10) Please, indicate the improvement level in your company of the following performance indicators during the last 3 years:
* Scale: from 1 (worsened significantly) to 5 (improved significantly)
a) Productivity ( )
b) Quality ( )
c) Costs ( )
d) Customer/Patient Satisfaction ( )

5 INTEGRATING LEAN AND RESILIENCE: A HEALTHCARE SUPPLY CHAIN PERSPECTIVE

Abstract: The objective of this phase is to analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios. The study addresses the gap in how different tier levels of the healthcare supply chain integrate lean and resilience. Employing a case study approach, the research evaluated four Italian organizations (two healthcare providers, one pharmaceutical distributor, and one pharmaceutical producer) representing the three main tier levels of the healthcare supply chain. The methodology involved a questionnaire assessing the adoption of specific lean practices and resilience capabilities, followed by a scenario analysis by experts used to identify critical practices and capabilities across different disruptive scenarios. This research highlighted the critical roles of JIT practice and anticipation capability in the healthcare supply chain. The study contributes to the fields of supply chain management and healthcare by systematically identifying and classifying the importance of lean practices and resilience capabilities in managing disruptions. Additionally, the potential for cross-tier collaboration and knowledge sharing to enhance overall supply chain resilience is highlighted.

Keywords: Lean healthcare; Healthcare; Supply Chain; Resilience; Disruption.

5.1 INTRODUCTION

Lean supply chain consists of organizations directly linked by upstream and downstream flows of goods, services and information that work together to reduce costs and waste by fulfilling the essential needs of customers (Núñez-Merino *et al.,* 2020). Within various industry sectors, the healthcare supply chain emerges as a pivotal application of lean, given its paramount role in safeguarding and enhancing human lives (Khorasani *et al*., 2020). However, some disruptive events such as COVID-19 outbreak on healthcare operations has raised many questions about the lean applicability and capacity of healthcare to respond to critical events (Ivanov, 2021). These concerns stem from potential operational adjustments linked to the adoption of lean practices, including significant reductions in inventory levels and a noticeable lack of redundancy, which can affect the resilience of the supply chain (Ruiz-Benítez et al., 2018).

Contrastingly, some scholars highlight a significant synergy between lean and resilience in the healthcare supply chain. Leite (2022) affirms the positive impact of lean practices on resilience during disruptive events, emphasizing their crucial role in supporting healthcare organizations in critical situations. Additionally, Kuiper *et al*. (2022) argue that lean methodologies can alter underlying trade-offs, making healthcare continuity more robust against catastrophic events, and thereby increasing resilience. In line with this, Birkie (2016) reported a positive product synergy between resilience and lean practices when confronted with disruptions of varying natures and intensities. This implies that the combined effect of lean and resilience is complementary, surpassing the benefits of each approach individually and resulting in enhanced operational performance (Birkie, 2016).

Despite the presence of evidence supporting a positive relationship between lean and resilience, the literature reveals a notable scarcity of studies specifically addressing their combined application within the healthcare supply chain (Habibi Rad *et al.,* 2021). This gap is especially evident in analyses that dissect how these practices are implemented across the different tier levels of the healthcare supply chain (Alemsan *et al.,* 2022). Furthermore, the literature lacks comprehensive exploration of how lean and resilience are addressed in the face of disruptive scenarios, such as pandemics or supply chain crises (De Sanctis *et al.,* 2018). This situation underscores the following research question: "How does the deployment of lean practices and resilience capabilities vary within the healthcare supply chain across different disruptive scenarios?" Therefore, the objective of this study is to analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios. To achieve this, a case study was conducted involving four organizations from the Italian healthcare supply chain, which are categorized into three tier levels.

This study presents theoretical and practical contributions. Theoretically, it advances the understanding of the interaction between lean practices and resilience capabilities within the healthcare supply chain, particularly during disruptions. It adds to the literature by examining the implementation of these practices and capabilities across different tier levels, providing insights into their synergistic potential. Practically, this study provides valuable information to help formulate strategies that guide managers towards more efficient and resilient supply chain operations. Furthermore, the study enables a systemic view of the healthcare supply chain, encouraging an understanding of how each organization contributes to the whole, rather than focusing solely on individual organizational performance.

The article is structured as follows: Section 5.2. provides a Theoretical Review, 5.3 Section presents the Method, Section 5.4 presents the Results and Discussions, and Section 5.5 concludes with Final Considerations.

5.2 THEORETICAL REVIEW

5.2.1 Lean and Resilience in the Healthcare Supply Chain

The discourse surrounding resilience in the healthcare supply chain has gained significant traction, especially in light of the COVID-19 pandemic (Spieski *et al.,* 2022). Among the myriad strategies for enhancing resilience in the healthcare supply chain, Rehman and Ali (2022) propose that Industry 4.0, multiple sourcing, risk awareness, agility, and global diversification of suppliers, markets, and operations are the most significant strategies to enhance healthcare resilience. Following this perspective, Furstenau *et al.* (2022) expand on the adoption of digital technologies such as big data analytics, predictive health data analysis, and remote monitoring of inventories to improve resilience in the healthcare supply chain.

Concurrently, lean practices have been recognized for their potential to bolster supply chain resilience through improved coordination, communication, capacity building, and awareness (Hussain *et al*., 2022). In the healthcare supply chain context, Yilmaz *et al*. (2023) introduce an optimization-based methodology utilizing lean practices and emphasize the importance of employing a pre-disruption strategy via the proposed methodology to design a resilient supply chain to be prepared for disruptions. Also, Alemsan and Tortorella (2022) confirmed the correlation between resilience and lean and the mediating role of resilience development in the association between lean principles adoption and operational performance. In addition, Rosso and Saurin (2018) argued that the joint use of lean practices can effectively address the efficiency-thoroughness trade-off in complex systems, thereby enhancing resilience.

Furthermore, it can be observed an application of lean and resilience at different healthcare supply chain tier levels. For example, at the upstream level, Saraji *et al.* (2023) introduced a framework for assessing pharmaceutical companies' performance in lean, agile, resilience, and green adoption, emphasizing design for manufacturing and strong communication with suppliers as critical challenges. On the downstream level of the healthcare supply chain, Samieinasab *et al.* (2022) proposed a comprehensive framework for evaluating and enhancing clinical department performance by integrating resilience and lean principles and they find the need for a balanced approach, as clinics demonstrating excellent resilience performance may lack lean performance, and vice versa.

5.2.2 Supply Chain Disruptions

Systems with many elements as supply chains can be vulnerable to nonlinear interactions as disruptions and causing severe impacts. (Pettit *et al*., 2013). Supply chain disruptions can be defined by unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain (Macdonald; Corsi, 2013). The disruption process starts with its identification and understanding, progresses through recovery efforts, and concludes with restoration and subsequent redesign measures to enhance the process (Messina *et al.,* 2020). The decisions made by supply chain managers greatly influence the speed and efficacy of the recovery process (Shekarian; Mellat Parast, 2021). Therefore, effective management of disruptions is crucial for maintaining the resilience and smooth operation of supply chain systems in the face of unexpected events (Birkie; Trucco, 2017).

Disruptions can be classified based on their origin, such as internal and external disruptions. For instance, internal disruptions stem from failures or resource issues within a company, while external disruptions result from events beyond the supply chain, including natural disasters, political instability, terrorism, and global financial crises (Park *et al*., 2016). Furthermore, disruptions can also be categorized by their causes, including natural, technological, economic, and political disruptions (Peck, 2005). Additionally, disruptions can be classified by their impact on the supply chain, encompassing issues like raw material availability, production interruptions, delivery delays, quality problems, and supply chain failures (Macdonald; Corsi, 2013).

Another possible classification of disruptions in supply chains is based on their occurrence probability and consequences. Sheffi and Rice (2005) proposed a matrix that categorizes disruptions into four vulnerability quadrants as shown in Figure 7. Low probability and low consequence events could include equipment failures, sporadic supplier issues, small security incidents, and minor deviations in product quality (Quadrant 1). High probability but low consequence events could include minor logistical delays, temporary shortages of non-critical medical supplies and brief communication disruptions (Quadrant 2). Low probability but high consequence events, such as severe natural disasters, pandemics, terrorist attacks, and major recalls of medical products, are rare but can severely affect the system (Quadrant 3). High probability and high consequence can include events include worker strikes, IT system failures, delays in the delivery of critical medications, and supply chain disruptions for essential medical equipment (Quadrant 4).

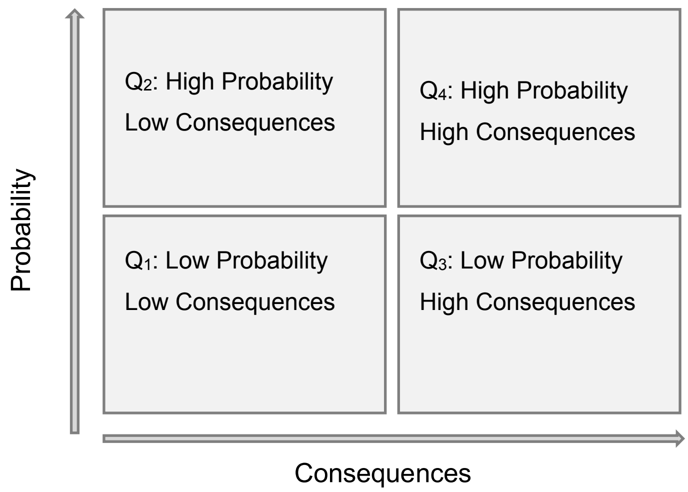

Figure 7 - Disruptions Classification (Adapted from Sheffi and Rice, 2005)

Considering the classifications of supply chain disruptions, healthcare systems emerge as particularly vulnerable to such events, with severe implications for service performance (Samieinasab *et al*., 2022). For instance, a halt in pharmaceutical production due to regulatory changes or geopolitical tensions can quickly lead to shortages of essential medications, compelling healthcare providers to seek alternative treatments, potentially at higher costs and with less efficacy (Roscoe *et al*., 2020). Similarly, natural disasters can disrupt the logistics of medical supply delivery, leading to critical delays in treatments and surgeries (Razavi *et al.,* 2021). Additionally, strikes or labor disputes in key logistics sectors can interrupt the flow of critical supplies, leading to operational bottlenecks and compromised patient care (Youssef *et al.,* 2021).

5.3 METHOD

To achieve the objective of this study, a case study is conducted. According to Yin (2015), the case study is a research strategy that allows an in-depth and detailed investigation of a phenomenon in its natural context. The study consists of four steps: (*i*) defining the assessment criteria for lean and resilience; (*ii*) selecting the healthcare supply chain organizations to be evaluated (*iii*) assessing the importance level of each lean practice and each resilience capability across different disruptive scenarios, and (*iv*) determining the most critical lean practices and resilience capabilities.

5.3.1 Defining the assessment criteria for lean and resilience

A questionnaire is prepared to assess the level of adoption of lean practices and resilience capabilities within the organizations. The selected lean practices and resilience capabilities is based on the framework developed by Alemsan *et al*. (2022). For lean adoption assessment, the questionnaire includes the following lean practices: value stream mapping (VSM), visual management, A3, standardized work, pull system, kanban, 5s, departmental layout, vendor managed inventory (VMI), inventory management, spaghetti diagram, just-in-time, continuous improvement, kaizen, radio frequency identification (RFID), autonomation, six-sigma, and poka-yoke. Regarding resilience adoption assessment, the questionnaire has the following resilience capabilities: flexibility, capacity, efficiency, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organization, market position, security/safety, and financial strength. Participants will be asked to rate the level of adoption for each lean practice and resilience capability on a Likert scale from 1 (‘it has never been used in my organization’) to 5 (‘it is currently used practically throughout the organization’). The questionnaire is included in Appendix A.

5.3.2 Selecting the healthcare supply chain organizations to be evaluated

Moons et al. (2019) define three main tier levels of the healthcare supply chain: the producers (e.g., medical device manufacturers, pharmaceutical companies, etc.), purchasers (e.g., purchasing organizations, distributors, etc.), and healthcare providers (e.g., hospitals, clinics). The chosen organizations must represent these three main tier levels of the healthcare supply chain as described by Moons *et al.* (2019). Additionally, it is mandatory for the organizations to have prior experience with lean implementation. Regarding the respondents, it is a requirement that they are employees who have actively participated in lean projects. Furthermore, it is highly desirable to form a diverse and multidisciplinary group of respondents, including individuals from various positions and sectors such as medical directors, nursing coordinators and planning managers.

To ensure effective collaboration, the selected organizations must establish interconnectedness by belonging to the same healthcare supply chain. The connection will be particularly facilitated through the flow of medicines, serving as a crucial point of intersection among them. The choice of focusing on the medicines flow is motivated by several reasons. Firstly, medicines flow plays a critical role in the healthcare supply chain as it directly impacts the quality of patient care (Iqbal et al., 2017). Also, the availability, quality, and safety of medicines are fundamental for ensuring the success of treatments (Khorasani *et al*., 2020). Moreover, the medicines flow significantly influences healthcare costs, encompassing expenses related to the drugs themselves, as well as transportation, storage, and inventory management costs (D’Ambrosio *et al*., 2020). Finally, the complexity of medicines flow is high due to the wide variety of medications involved and the involvement of multiple stakeholders, from manufacturers to patients (Merkuryeva *et al.,* 2019).

5.3.3 Assessing the importance level of each lean practice and each resilience capability across different disruptive scenarios

Based on the work of Sheffi and Rice (2005), four disruption scenarios were identified as described in Section 5.2.2 of this article. The aim of this step is to assess how each lean practice and resilience capability stand up against various disruptive scenarios. Participants evaluate and assign a level of importance, ranging from 1 (least important) to 5 (most important), to each identified lean practice and resilience capability within the context of these scenarios. To ensure the highest level of expertise, eight academics who actively work and research in the investigated phenomenon are invited to share their opinions. This helps secure in-depth and legitim insights related to the topic. To achieve a balanced and representative analysis, the median of the assigned importance levels is calculated for each practice and capability.

5.3.4 Determining the most critical lean practices and resilience capabilities

From the results of the questionnaire about the adoption level, the median of the lean practices values is identified. Subsequently, the adoption slack is calculated by subtracting the median from 5 (Equation 1), aiming to quantify the gap between the current adoption level and the ideal state. The adoption slack highlights the potential for improvement in the adoption of lean practices and resilience capabilities. The adoption slack is then multiplied by the importance level of each lean practice generating the criticality factor (Equation 2). This step will generate four columns of data for each organization, one for each disruption scenario, which will then be standardized (Equation 3). Through standardization, the most critical items for each organization and scenario will be identified, specifically those items with values greater than 1 (Tortorella; Fogliatto, 2014). These items are deemed critical because, despite their recognized importance, they are not sufficiently adopted within the organization, indicating a significant potential for operational improvement. The equations involving resilience capabilities are similar and they are showed in Equations 4, 5 and 6.

$$a_i = 5 - m_i \qquad i = 1, \dots, 18 \qquad (1)$$

$$C_{ij} = a_i \times s_{ij,} \qquad i = 1, \dots, 18 \text{ and } j = 1, \dots, 4 \qquad (2)$$

$$ZC_{ij} = \frac{C_{ij} - \bar{C}}{\sigma} \qquad i = 1, \dots, 18 \text{ and } j = 1, \dots, 4 \qquad (3)$$

Where:
a_i : $lean\ adoption\ slack$
m_i : $median\ of adoption\ level\ of\ a\ lean\ practice$
C_{ij}: $criticality\ factor$
s_{ij}: $median\ of\ importance\ level\ of\ a\ lean\ practice\ in\ the\ disruptive\ scenarios$
$\bar{C}$: $average\ of\ criticality\ factors$
σ: $standard\ deviation\ of\ criticality\ factors$
ZC_{ij}: $standardized\ criticality\ factor$

$$a_k = 5 - m_k \qquad k = 1, \dots, 13 \qquad (4)$$

$$C_{kj} = a_k \times s_{kj,} \qquad k = 1, \dots, 13 \text{ and } j = 1, \dots, 4 \qquad (5)$$

$$ZC_{kj} = \frac{C_{kj} - \bar{C}}{\sigma} \qquad k = 1, \dots, 13 \text{ and } j = 1, \dots, 4 \qquad (6)$$

Where:
a_k : $resilience\ adoption\ slack$
m_k : $median\ of adoption\ level\ of\ a\ resilience\ capability$
C_{kj}: $criticality\ factor$
s_{kj}: $median\ of\ importance\ level\ of\ a\ resilience\ capability\ in\ the\ disruptive\ scenarios$
$\bar{C}$: $average\ of\ criticality\ factors$
σ: $standard\ deviation\ of\ criticality\ factors$
ZC_{kj}: $standardized\ criticality\ factor$

5.4 RESULTS

5.4.1 Case study

In this section, the results are presented. Firstly, Italy was the country chosen for the application of the case studies due to several reasons. Italy was a country hard hit by the COVID-19 pandemic, which brought significant challenges to its healthcare supply chain (Remuzzi; Remuzzi, 2020). The manner in which Italy responded and adapted to the crisis, including reorganizing its healthcare supply chain, provided valuable insights to crisis management, resilience, and innovation under extreme disruptive events (Torri *et al*., 2020). In addition, Italy has an aging population (Spaccatini *et al*., 2022), which poses unique challenges for healthcare supply chain management. The case study focused on the medicine flow sector, where Italy plays a significant role and is considered one of the main players in the European pharmaceutical industry (Musazzi *et al*., 2020). The Italian pharmaceutical industry is second to the German one, as it represented 26% of total production and 19% of the market in the five biggest European Union countries (Toma, 2020). Also, in recent years Italian pharmaceutical exports grew by 56% compared to the European average of 33% (Toma, 2020). Therefore, the case study on the flow of medicines in Italy could offer valuable insights to the study.

The supply chain structure under study was composed of four organizations: two healthcare providers, a pharmaceutical distributor, and a pharmaceutical producer, as depicted in Figure 8.

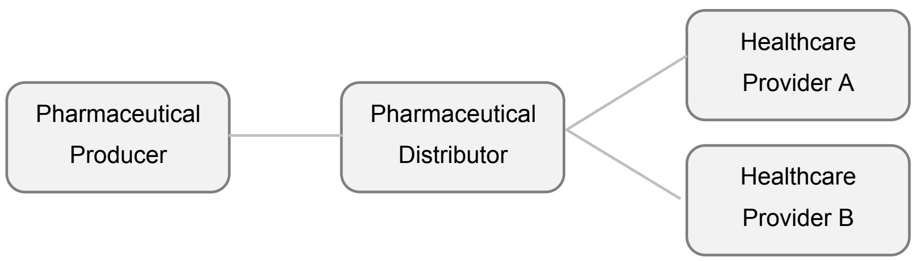

Figure 8 - Italian Supply Chain Structure

The *Healthcare Provider A* was the first hospital in Italy to effectively implement lean practices in the healthcare industry, receiving an award in recognition of its achievement. This award is organized by a consortium of prestigious Italian healthcare and educational organizations as the Italian Federation of Hospital Companies. Furthermore, the hospital boasts several noteworthy lean projects across the entire facility, with some being honored for their excellence. To ensure seamless implementation of the lean approach, the hospital has established a multidisciplinary lean team. As part of its commitment to continuous improvement, the hospital offers its employees courses on lean management, aimed at enhancing their knowledge and skills. This hospital is also among the largest healthcare facilities in Italy with 5,000 employees, and catering to more than 1,000 people per day, highlighting its extensive reach and impact in the sector.

The *Healthcare Provider B* has a different structure. The company is responsible for providing medical care and health services to a population of 400,000 people and is made up of 13 operating units, including clinics and health centers. The healthcare company won the Lean Healthcare Award for the best project undertaken in the last two years and for the best project idea under implementation. In addition, this hospital was nationally recognized as one of the most advanced hospitals in lean healthcare.

The selected *Pharmaceutical Distributor* maintains a strong connection with both healthcare providers as it is the sole distributor of medicines for both institutions. In addition to handling procurement, warehousing, and distribution logistics, this pharmaceutical distributor is also responsible for managing tender procedures and implementing advanced information and communication technologies for hospitals. Furthermore, the Pharmaceutical Distributor and Healthcare Provider A have established a partnership with a local university to support a master program focused on Lean Healthcare. This collaborative initiative underscores the organizations' shared commitment to improving healthcare quality and efficiency in the region.

The organization selected to represent the *Pharmaceutical Producer* is one of the largest pharmaceutical companies in Italy with approximately 7,000 employees, boasting a revenue of over 2 billion euros. The company has been applying lean management for years and offers its employees a variety of lean certification programs, such as Lean Six Sigma Belt certifications.

5.4.2 Data collection and criticality of lean practices and resilience capabilities

Following the selection of organizations, a total of 100 responses were collected from employees of these four organizations. The data collection occurred between April and July 2023. The methods of communication included LinkedIn, email, and coordination with a designated representative from each organization, which facilitated internal dissemination of the questionnaire. The respondents’ data is included in Table 14.

Table 14 - Respondents Data

Organization	Respondents	Experience in the organization		Experience with Lean	
		More than 2 years	Less than 2 years	More than 2 years	Less than 2 years
Pharmaceutical Producer	20	65%	35%	75%	25%
Pharmaceutical Distributor	20	80%	20%	75%	25%
Healthcare Provider A	30	60%	40%	50%	50%
Healthcare Provider B	30	77%	23%	60%	40%

From the results of the questionnaire, Table 15 and Table 16 provide the data derived from the equations detailed in the Method Section. In gray, there are the most critical lean practices and resilience capabilities for each scenario of disruption, identifying those with a standardized criticality factor (ZC) exceeding 1. Statistically, a ZC greater than 1 signifies that the associated value is more than one standard deviation above the dataset's mean, marking the practice or capability as significantly critical. Such a ZC indicates the imperative areas where enhancing adoption could result in substantial improvements, given the pre-established importance of these items.

Table 15 allows the identification of the most critical lean practices across four organizations and four disruptive scenarios. Eleven different lean practices were identified as critical, such as JIT, lean six-sigma, and poka-yoke, indicating areas where improvements could yield substantial operational benefits. Additionally, Table 16 shows the criticality levels for resilience capabilities. The analysis reveals that only six of these thirteen capabilities are considered critical, distributed across the four organizations and four disruptive scenarios, highlighting specific areas where improvements are necessary to enhance organizational resilience. The identified critical resilience capabilities are anticipation, recovery, adaptability, organization, financial strength, and collaboration.

Table 15 - Criticality assessment for Lean Practices

					Pharmaceutical Producer									Pharmaceutical Distributor									Healthcare Provider A									Healthcare Provider B								
Lean	S_1	S_2	S_3	S_4	a_i	C_{i1}	C_{i2}	C_{i3}	C_{i4}	ZC_{i1}	ZC_{i2}	ZC_{i3}	ZC_{i4}	a_i	C_{i1}	C_{i2}	C_{i3}	C_{i4}	ZC_{i1}	ZC_{i2}	ZC_{i3}	ZC_{i4}	a_i	C_{i1}	C_{i2}	C_{i3}	C_{i4}	ZC_{i1}	ZC_{i2}	ZC_{i3}	ZC_{i4}	a_i	C_{i1}	C_{i2}	C_{i3}	C_{i4}	ZC_{i1}	ZC_{i2}	ZC_{i3}	ZC_{i4}
I_1	3.0	4.5	4.5	5.0	2.0	6.0	9.0	9.0	10.0	0.27	0.65	0.26	0.31	4.00	12.00	18.00	18.00	20.00	0.79	1.52	0.94	1.16	1.00	3.00	4.50	4.50	5.00	-0.59	-0.25	-0.61	-0.58	1.50	4.50	6.75	6.75	7.50	-0.75	-0.52	-0.81	-0.81
I_2	2.5	4.0	4.0	5.0	1.0	2.5	4.0	4.0	5.0	-1.16	-0.97	-1.19	-1.01	2.00	5.00	8.00	8.00	10.00	-1.23	-1.01	-1.35	-1.17	1.00	2.50	4.00	4.00	5.00	-1.00	-0.60	-0.85	-0.58	2.00	5.00	8.00	8.00	10.00	-0.54	-0.04	-0.46	-0.11
I_3	3.0	4.0	4.0	5.0	3.0	9.0	12.0	12.0	15.0	1.50	1.62	1.12	1.63	4.00	12.00	16.00	16.00	20.00	0.79	1.01	0.48	1.16	1.00	3.00	4.00	4.00	5.00	-0.59	-0.60	-0.85	-0.58	1.00	3.00	4.00	4.00	5.00	-1.40	-1.57	-1.58	-1.50
I_4	3.5	3.5	4.5	5.0	1.0	3.5	3.5	4.5	5.0	-0.75	-1.14	-1.04	-1.01	2.00	7.00	7.00	9.00	10.00	-0.65	-1.27	-1.12	-1.17	1.00	3.50	3.50	4.50	5.00	-0.18	-0.94	-0.61	-0.58	2.00	7.00	7.00	9.00	10.00	0.32	-0.43	-0.18	-0.11
I_5	2.5	3.0	4.0	4.0	2.0	5.0	6.0	8.0	8.0	-0.14	-0.32	-0.03	-0.22	3.50	8.75	10.50	14.00	14.00	-0.15	-0.38	0.02	-0.24	1.50	3.75	4.50	6.00	6.00	0.02	-0.25	0.11	-0.11	2.50	6.25	7.50	10.00	10.00	0.00	-0.23	0.10	-0.11
I_6	3.0	4.0	4.0	5.0	2.0	6.0	8.0	8.0	10.0	0.27	0.32	-0.03	0.31	3.00	9.00	12.00	12.00	15.00	-0.08	0.00	-0.44	0.00	1.00	3.00	4.00	4.00	5.00	-0.59	-0.60	-0.85	-0.58	3.00	9.00	12.00	12.00	15.00	1.18	1.49	0.66	1.28
I_7	3.0	4.0	5.0	5.0	1.0	3.0	4.0	5.0	5.0	-0.95	-0.97	-0.90	-1.01	4.00	12.00	16.00	20.00	20.00	0.79	1.01	1.40	1.16	1.00	3.00	4.00	5.00	5.00	-0.59	-0.60	-0.37	-0.58	2.00	6.00	8.00	10.00	10.00	-0.11	-0.04	0.10	-0.11
I_8	2.0	2.5	4.0	4.0	2.0	4.0	5.0	8.0	8.0	-0.54	-0.65	-0.03	-0.22	2.00	4.00	5.00	8.00	8.00	-1.52	-1.77	-1.35	-1.64	1.00	2.00	2.50	4.00	4.00	-1.41	-1.63	-0.85	-1.05	2.00	4.00	5.00	8.00	8.00	-0.97	-1.19	-0.46	-0.67
I_9	2.0	3.5	4.0	4.5	3.0	6.0	10.5	12.0	13.5	0.27	1.14	1.12	1.23	3.50	7.00	12.25	14.00	15.75	-0.65	0.06	0.02	0.17	2.00	4.00	7.00	8.00	9.00	0.23	1.48	1.06	1.29	3.00	6.00	10.50	12.00	13.50	-0.11	0.91	0.66	0.86
I_{10}	4.0	5.0	5.0	5.0	1.0	4.0	5.0	5.0	5.0	-0.54	-0.65	-0.90	-1.01	2.00	8.00	10.00	10.00	10.00	-0.37	-0.51	-0.89	-1.17	1.00	4.00	5.00	5.00	5.00	0.23	0.10	-0.37	-0.58	2.00	8.00	10.00	10.00	10.00	0.75	0.72	0.10	-0.11
I_{11}	2.0	3.0	3.0	3.5	3.0	6.0	9.0	9.0	10.5	0.27	0.65	0.26	0.44	4.00	8.00	12.00	12.00	14.00	-0.37	0.00	-0.44	-0.24	1.00	2.00	3.00	3.00	3.50	-1.41	-1.29	-1.32	-1.28	2.00	4.00	6.00	6.00	7.00	-0.97	-0.81	-1.02	-0.95
I_{12}	3.5	4.0	5.0	5.0	3.0	10.5	12.0	15.0	15.0	2.11	1.62	1.99	1.63	4.00	14.00	16.00	20.00	20.00	1.37	1.01	1.40	1.16	1.00	3.50	4.00	5.00	5.00	-0.18	-0.60	-0.37	-0.58	3.00	10.50	12.00	15.00	15.00	1.83	1.49	1.50	1.28
I_{13}	4.0	4.5	4.5	5.0	1.0	4.0	4.5	4.5	5.0	-0.54	-0.81	-1.04	-1.01	2.50	10.00	11.25	11.25	12.50	0.21	-0.19	-0.61	-0.59	1.00	4.00	4.50	4.50	5.00	0.23	-0.25	-0.61	-0.58	1.00	4.00	4.50	4.50	5.00	-0.97	-1.38	-1.44	-1.50
I_{14}	4.0	4.5	4.5	4.5	2.0	8.0	9.0	9.0	9.0	1.09	0.65	0.26	0.04	4.00	16.00	18.00	18.00	18.00	1.95	1.52	0.94	0.70	1.50	6.00	6.75	6.75	6.75	1.86	1.31	0.46	0.24	1.50	6.00	6.75	6.75	6.75	-0.11	-0.52	-0.81	-1.02
I_{15}	1.5	2.5	3.5	4.0	3.0	4.5	7.5	10.5	12.0	-0.34	0.16	0.69	0.84	4.00	6.00	10.00	14.00	16.00	-0.94	-0.51	0.02	0.23	2.50	3.75	6.25	8.75	10.00	0.02	0.96	1.42	1.76	2.50	3.75	6.25	8.75	10.00	-1.08	-0.71	-0.25	-0.11
I_{16}	2.0	3.0	4.0	4.5	1.0	2.0	3.0	4.0	4.5	-1.36	-1.30	-1.19	-1.14	2.00	4.00	6.00	8.00	9.00	-1.52	-1.52	-1.35	-1.40	2.00	4.00	6.00	8.00	9.00	0.23	0.79	1.06	1.29	3.00	6.00	9.00	12.00	13.50	-0.11	0.34	0.66	0.86
I_{17}	3.0	3.5	5.0	5.0	1.0	3.0	3.5	5.0	5.0	-0.95	-1.14	-0.90	-1.01	4.00	12.00	14.00	20.00	20.00	0.79	0.51	1.40	1.16	2.00	6.00	7.00	10.00	10.00	1.86	1.48	2.01	1.76	3.50	10.50	12.25	17.50	17.50	1.83	1.58	2.20	1.97
I_{18}	3.0	3.5	4.5	4.5	3.0	9.0	10.5	13.5	13.5	1.50	1.14	1.56	1.23	4.00	12.00	14.00	18.00	18.00	0.79	0.51	0.94	0.70	2.00	6.00	7.00	9.00	9.00	1.86	1.48	1.53	1.29	3.00	9.00	10.50	13.50	13.50	1.18	0.91	1.08	0.86

Notes: I_1 VSM; I_2 Visual Management; I_3 A3; I_4 Standardized Work; I_5 Pull System; I_6 Kanban; I_7 5S; I_8 Departmental Layout; I_9 VMI; I_{10} Inventory Management; I_{11} Spaghetti diagram; I_{12} Just-in-time; I_{13} Continuous Improvement; I_{14} Kaizen; I_{15} RFID; I_{16} Autonomation; I_{17} Six-sigma; I_{18} Poka-yoke.

*Gray cells indicate the most critical lean practices for each disruption scenario, with a standardized criticality factor (ZC) exceeding 1.

Table 16 - Criticality assessment for Resilience Capabilities

	S_1	S_2	S_3	S_4	Pharmaceutical Producer a_k	C_{k1}	C_{k2}	C_{k3}	C_{k4}	ZC_{k1}	ZC_{k2}	ZC_{k3}	ZC_{k4}	Pharmaceutical Distributor a_k	C_{k1}	C_{k2}	C_{k3}	C_{k4}	ZC_{k1}	ZC_{k2}	ZC_{k3}	ZC_{k4}
r_1	3.0	4.0	4.5	5.0	2.00	6.00	8.00	9.00	10.00	0.61	0.57	0.72	0.75	2.00	6.00	8.00	9.00	10.00	-0.72	-0.74	-0.52	-0.55
r_2	3.0	4.5	4.5	5.0	1.00	3.00	4.50	4.50	5.00	-0.64	-0.49	-0.57	-0.55	2.00	6.00	9.00	9.00	10.00	-0.72	-0.34	-0.52	-0.55
r_3	3.0	4.5	4.5	5.0	2.00	6.00	9.00	9.00	10.00	0.61	0.87	0.72	0.75	2.50	7.50	11.25	11.25	12.50	0.03	0.55	0.34	0.38
r_4	2.5	3.5	4.0	4.0	2.00	5.00	7.00	8.00	8.00	0.19	0.27	0.43	0.23	2.50	6.25	8.75	10.00	10.00	-0.60	-0.44	-0.14	-0.55
r_5	3.0	4.0	4.0	5.0	2.00	6.00	8.00	8.00	10.00	0.61	0.57	0.43	0.75	3.00	9.00	12.00	12.00	15.00	0.78	0.84	0.63	1.30
r_6	3.5	4.5	5.0	5.0	2.00	7.00	9.00	10.00	10.00	1.02	0.87	1.00	0.75	3.50	12.25	15.75	17.50	17.50	2.40	2.32	2.74	2.22
r_7	3.5	4.5	5.0	5.0	2.00	7.00	9.00	10.00	10.00	1.02	0.87	1.00	0.75	2.00	7.00	9.00	10.00	10.00	-0.22	-0.34	-0.14	-0.55
r_8	3.0	4.0	4.0	5.0	2.00	6.00	8.00	8.00	10.00	0.61	0.57	0.43	0.75	2.50	7.50	10.00	10.00	12.50	0.03	0.05	-0.14	0.38
r_9	3.0	4.5	4.5	5.0	2.00	6.00	9.00	9.00	10.00	0.61	0.87	0.72	0.75	2.50	7.50	11.25	11.25	12.50	0.03	0.55	0.34	0.38
r_{10}	4.0	4.5	4.5	5.0	1.00	4.00	4.50	4.50	5.00	-0.22	-0.49	-0.57	-0.55	2.50	10.00	11.25	11.25	12.50	1.28	0.55	0.34	0.38
r_{11}	2.5	3.5	3.5	4.0	0.00	0.00	0.00	0.00	0.00	-1.89	-1.85	-1.86	-1.86	2.50	6.25	8.75	8.75	10.00	-0.60	-0.44	-0.62	-0.55
r_{12}	3.0	3.5	4.5	4.5	1.00	3.00	3.50	4.50	4.50	-0.64	-0.79	-0.57	-0.68	1.50	4.50	5.25	6.75	6.75	-1.47	-1.82	-1.39	-1.74
r_{13}	3.5	4.0	4.0	5.0	0.00	0.00	0.00	0.00	0.00	-1.89	-1.85	-1.86	-1.86	2.00	7.00	8.00	8.00	10.00	-0.22	-0.74	-0.91	-0.55

	S_1	S_2	S_3	S_4	Healthcare Provider A a_k	C_{k1}	C_{k2}	C_{k3}	C_{k4}	ZC_{k1}	ZC_{k2}	ZC_{k3}	ZC_{k4}	Healthcare Provider B a_k	C_{k1}	C_{k2}	C_{k3}	C_{k4}	ZC_{k1}	ZC_{k2}	ZC_{k3}	ZC_{k4}
r_1	3.0	4.0	4.5	5.0	2.00	6.00	8.00	9.00	10.00	0.43	0.56	0.75	0.76	2.00	6.00	8.00	9.00	10.00	-0.17	-0.14	0.08	0.13
r_2	3.0	4.5	4.5	5.0	1.00	3.00	4.50	4.50	5.00	-1.26	-1.11	-1.17	-1.18	2.00	6.00	9.00	9.00	10.00	-0.17	0.32	0.08	0.13
r_3	3.0	4.5	4.5	5.0	1.00	3.00	4.50	4.50	5.00	-1.26	-1.11	-1.17	-1.18	2.00	6.00	9.00	9.00	10.00	-0.17	0.32	0.08	0.13
r_4	2.5	3.5	4.0	4.0	1.00	2.50	3.50	4.00	4.00	-1.54	-1.59	-1.39	-1.57	2.00	5.00	7.00	8.00	8.00	-0.73	-0.60	-0.33	-0.73
r_5	3.0	4.0	4.0	5.0	2.00	6.00	8.00	8.00	10.00	0.43	0.56	0.32	0.76	2.00	6.00	8.00	8.00	10.00	-0.17	-0.14	-0.33	0.13
r_6	3.5	4.5	5.0	5.0	2.00	7.00	9.00	10.00	10.00	1.00	1.04	1.17	0.76	3.00	10.50	13.50	15.00	15.00	2.35	2.40	2.55	2.28
r_7	3.5	4.5	5.0	5.0	2.00	7.00	9.00	10.00	10.00	1.00	1.04	1.17	0.76	2.00	7.00	9.00	10.00	10.00	0.39	0.32	0.49	0.13
r_8	3.0	4.0	4.0	5.0	2.00	6.00	8.00	8.00	10.00	0.43	0.56	0.32	0.76	2.00	6.00	8.00	8.00	10.00	-0.17	-0.14	-0.33	0.13
r_9	3.0	4.5	4.5	5.0	2.00	6.00	9.00	9.00	10.00	0.43	1.04	0.75	0.76	2.00	6.00	9.00	9.00	10.00	-0.17	0.32	0.08	0.13
r_{10}	4.0	4.5	4.5	5.0	1.50	6.00	6.75	6.75	7.50	0.43	-0.04	-0.21	-0.21	2.00	8.00	9.00	9.00	10.00	0.95	0.32	0.08	0.13
r_{11}	2.5	3.5	3.5	4.0	1.00	2.50	3.50	3.50	4.00	-1.54	-1.59	-1.60	-1.57	1.00	2.50	3.50	3.50	4.00	-2.13	-2.22	-2.19	-2.45
r_{12}	3.0	3.5	4.5	4.5	2.00	6.00	7.00	9.00	9.00	0.43	0.08	0.75	0.37	2.00	6.00	7.00	9.00	9.00	-0.17	-0.60	0.08	-0.30
r_{13}	3.5	4.0	4.0	5.0	2.00	7.00	8.00	8.00	10.00	1.00	0.56	0.32	0.76	2.00	7.00	8.00	8.00	10.00	0.39	-0.14	-0.33	0.13

Notes: r_1 Flexibility ; r_2 Capacity; r_3 Efficiency; r_4 Visibility; r_5 Adaptability; r_6 Anticipation; r_7 Recovery; r_8 Dispersion; r_9 Collaboration ; r_{10} Organization; r_{11} Market Position; r_{12} Security; r_{13} Financial Strength.

*Gray cells indicate the most critical lean practices for each disruption scenario, with a standardized criticality factor (ZC) exceeding 1.

Table 17 improves the visibility of the data from Table 15 ad Table 16 by presenting the most critical lean practices and resilience capabilities for each organization and each disruptive scenario in a consolidated manner. This table provides a clearer overview and facilitates easier comparison across different scenarios and organizations.

Table 17 - The most critical Lean practices and resilience capabilities for each organization and each disruptive scenario

		Disruptive Scenario 1 (low consequence low probability)	Disruptive Scenario 2 (low consequence high probability)	Disruptive Scenario 3 (high consequence low probability)	Disruptive Scenario 4 (high consequence high probability)
Pharmaceutical Producer	Lean	A3 JIT Kaizen Poka-Yoke	A3 VMI JIT Poka-Yoke	A3 VMI JIT Poka-Yoke	A3 VMI JIT Poka-Yoke
	Resilience	Anticipation Recovery		Anticipation Recovery	
Pharmaceutical Distributor	Lean	JIT Kaizen	VSM A3 5S JIT Kaizen	5S JIT Six-Sigma	VSM A3 5S JIT Six-Sigma
	Resilience	Anticipation Organization	Anticipation	Anticipation	Anticipation Adaptability
Healthcare Provider A	Lean	Kaizen Six-Sigma Poka-Yoke	VMI Kaizen Six-Sigma Poka-Yoke	VMI RFID Autonomation Six-Sigma Poka-Yoke	VMI RFID Autonomation Six-Sigma Poka-Yoke
	Resilience	Anticipation Recovery Financial Strength	Anticipation Recovery	Anticipation Recovery	Anticipation Recovery
Healthcare Provider B	Lean	Kanban JIT Six-Sigma Poka-Yoke	Kanban JIT Six-Sigma	JIT Six-Sigma Poka-Yoke	Kanban JIT Six-Sigma
	Resilience	Anticipation	Anticipation	Anticipation	Anticipation

5.4.3 Within case analysis

Pharmaceutical Producer

The identification of poka-yoke, A3, and JIT as critical practices across all scenarios for the Pharmaceutical Producer highlights the need to bolster quality control, enhance problem-solving capabilities, and improve operational efficiency. The underutilization of poka-yoke practice might result from a lack of comprehensive training or understanding of its error-prevention benefits in a sector where errors can have significant implications. The rarity of A3 practice might reflect an organizational environment not fully embracing structured problem-solving or a deficiency in skills necessary for facilitating these processes effectively. Lastly, the limited adoption of JIT practice suggests the difficulty in aligning its principles of lean inventory with the unpredictable demands and strict regulations of pharmaceutical production.

Regarding resilience, in scenarios of high probability, no resilience capability was considered critical. This suggests that, in both situations characterized by frequent fluctuations, the most crucial resilience capabilities might already be well adopted. The critical nature of anticipation and recovery capabilities in scenarios of low probability could be attributed to a general lack of preparedness for rare events. Organizations often focus on mitigating risks they frequently encounter, leading to well-established responses for common scenarios. However, rare events can catch these organizations off guard, necessitating a broader range of capabilities to effectively respond.

Pharmaceutical Distributor

The identification of JIT as a critical practice within a Pharmaceutical Distributor highlights a significant operational gap. This shortfall points to the necessity of creating a JIT culture more deeply within the organization to ensure timely medication delivery, crucial in the healthcare sector. Identifying A3 practice as critical in high probability scenarios highlights the need for structured problem-solving in frequently disrupted environments. A3 promotes in-depth analysis and evidence-based solutions, enabling organizations to effectively address and prevent recurring disruptions (Barros *et al*., 2021). Additionally, the presence of the 5S practice in the last three disruption scenarios highlights its crucial yet underdeveloped role in pharmaceutical distributor operations. 5S is vital for ensuring efficient, error-free distribution of medications, directly affecting patient care (Costa *et al.,* 2017) and its current underutilization, suggesting an opportunity to enhance their operational practices and maintain a safer and more productive work environment.

Regarding resilience, the criticality of anticipation capability in all scenarios underlines the foundational importance of forward-looking strategies to mitigate potential disruptions. It implies a strategic gap in the organization's current preparedness efforts, highlighting an area for immediate improvement. The mention of Organization capability in the first scenario points towards the need for well-defined processes, teamwork, training and a structured approach to manage and recover from minor disruptions efficiently. This capability is important for maintaining order and ensuring that operations can continue smoothly with minimal impact, even when disruptions are deemed unlikely and of low impact (Pettit *et al.,* 2013). The introduction of adaptability capability in the scenario with both high consequence and high probability highlights the need of the organization to be dynamically responsive in the face of significant and likely disruptions.

Healthcare Provider A

The analysis of lean practices and resilience capabilities across various disruptive scenarios reveals key insights for Healthcare Provider A as the consistency of lean six-sigma and poka-yoke practices emerging in all scenarios. The analysis suggests that, although these practices are highly valued for quality control strategies and error prevention, there are opportunities to broaden their adoption and amplify their benefits. This underutilization can often be attributed to several key factors. First, the complexity and perceived rigidity of implementing lean six-sigma and poka-yoke practices might deter organizations, particularly those with limited exposure to systematic quality improvement practices (Samanta; Gurumurthy, 2023). Also, the lack of awareness about the existence of lean six-sigma and poka-yoke practices could significantly contribute to their underutilization (Kumar; Steinebach, 2008). This gap in knowledge prevents organizations from even considering these practices as part of their quality control and error prevention strategies. Furthermore, the shortage of skilled practitioners who can lead such initiatives and mentor staff is another critical barrier, complicating the deployment of these methodologies in settings that could benefit from them the most (Vinod *et al.,* 2015).

Also, the kaizen practice is prominent in low consequence scenarios independent of probability. Despite its high valuation, kaizen underutilization points to a critical need for broader implementation, exacerbated by its limited recognition and understanding among hospital staff and management (Shatrov *et al.,* 2021). Without sufficient knowledge or training, the full spectrum of kaizen benefits might not be appreciated, which could result in reluctance to adopt the practice (Hasle *et al.,* 2016). Also, the upfront investment needed for training and process reengineering to implement Kaizen effectively can act as an obstacle, especially in hospitals where resources are limited (Harry, 2020).

For high consequence disruptive scenarios, VMI, RFID and autonomation are deemed critical. These practices are pivotal for ensuring that hospitals can maintain operational stability and continue to provide essential services during and after disruptions. Despite their significant potential for mitigating risks associated with such events, several factors contribute to their underutilization. First, the initial investment required for these technologies can be substantial, encompassing not only the cost of the technologies themselves but also the expense of integrating them into existing hospital operations (Dachyar; Yolanda, 2020). The integration of these practices into the hospital existing systems and processes involves a considerable degree of complexity. It requires a seamless blend of these technologies with current operational workflows, which can be challenging without the requisite technical expertise and IT infrastructure (Afoakwah *et al.,* 2023).

Regarding resilience capabilities, in the first scenario with low probability and low consequence, no capability was considered critical, indicating that the practices deemed most important are already widely adopted. The consistent presence of anticipation and recovery capabilities in the last three scenarios suggests their relevance and increasing importance in more complex and challenging situations. In high probability but low consequence scenarios, the ability to foresee and swiftly respond to a succession of minor disruptions is crucial for maintaining uninterrupted operations and ensuring that such events do not cumulatively degrade the system resilience (Safa *et al.,* 2021). Conversely, in scenarios marked by low probability and high consequence, the criticality of anticipation and recovery capabilities reflects the imperative to be well-prepared for rare but potentially devastating events (Sawyerr; Harrison, 2023). The analysis shows a clear need for better preparation for disruptions and quicker recovery after they happen. It suggests organization should both look ahead to spot possible disruptions through risk assessments and also have clear recovery plans ready for getting back to normal quickly once a disruption occurs (Senna *et al.,* 2023).

Healthcare Provider B

For Healthcare Provider B, an analysis uncovers the consistent underutilized roles of kanban and JIT practices for all scenarios. This underutilization likely stems from a lack of knowledge within the Healthcare Provider B about how these lean practices, which complement each other, can be effectively integrated into healthcare settings. JIT focuses on cutting inventory and lead times, while kanban enhances workflow efficiency, providing a robust method for hospitals to manage disruptions (Siddiqui, 2022). The insufficient adoption of these methodologies suggests a gap in understanding their combined potential to streamline operations, reduce waste, and ensure the availability of essential supplies precisely when needed, thereby maintaining continuity of care (Khorasani *et al*., 2021).

Regarding resilience capabilities, in all four disruption scenarios, the anticipation capability is consistently identified as both critical and underdeveloped within the healthcare system, indicating a systemic shortfall in the Healthcare Provider ability to foresee and prepare for potential disruptions. This gap, present across scenarios of varying probability and consequence, highlights a pressing need for the healthcare provider to enhance its predictive planning and risk assessment capabilities. The lack of anticipation capability suggests an organizational focus that may lean more towards reactive rather than proactive strategies, undermining the systems resilience and its ability to maintain operational stability and continuous patient care in the face of disruptions (Agostini *et al.,* 2023).

5.4.4 Healthcare supply chain analysis and discussions

In a broad analysis, it becomes apparent that JIT practice, with the exception of Healthcare Provider A which already exhibits high adoption, is significantly underutilized across the organizations within the healthcare supply chain. This disparity raises questions about the scalability and adaptability of JIT in environments characterized by unpredictable demands. According to the literature, Kaswan *et al*. (2022) highlight that failures in JIT execution often stem from a lack of insights into the enablers of successful implementation such as top management support, teamwork, and real-time information sharing. Similarly, Balkhi *et al.* (2022) identify that during the COVID-19 pandemic, shortages were exacerbated by JIT systems failing to meet unexpectedly high demands. This underlines the critical need for accurate demand forecasting. Furthermore, precise estimations of consumption patterns are essential, requiring robust tools to calculate and predict which items are at higher risk of shortage and which are not (Balkhi *et al.,* 2022). In the same way, Siddiqui (2022) cite some disadvantages of JIT as the limited room for error due to minimal stock levels maintained for re-working faulty products, and the highly vulnerability to disruptions from natural disasters. In sum, JIT just works properly when the organization has reliable and accurate demand forecasting and works with reliable suppliers (Balkhi *et al*., 2022). Therefore, while organizations may attempt to adopt JIT practice, they need these factors in place for it to be successful, which may justify the criticality indicated in this study.

Lean six-sigma practice is identified as critical in at least two scenarios for both healthcare providers and the pharmaceutical distributor but does not appear for the pharmaceutical producer. It is noteworthy that the producer consistently invests in six sigma training and projects for its employees, indicating a high level of integration and maturity in utilizing six-sigma methodologies within its operations. This situation contrasts with the healthcare providers and the pharmaceutical distributor, highlighting a discrepancy in the adoption and implementation of six- sigma across different segments of the supply chain. While the producer has effectively embedded lean six sigma principles to optimize quality and efficiency, healthcare providers and the distributor may not have reached the same level of implementation. Marolla *et al*. (2021) support these findings by attributing low adoption of lean six-sigma practices in three Italian public hospitals to barriers such as flawed integration of lean and six-sigma methodologies, exacerbated by complex healthcare structures. Additionally, Marolla *et al.* (2021) pinpoint critical factors such as the commitment of top and middle management, robust leadership, and also emphasize the importance of knowledge of statistical language and tools by the organizations. Building on these insights, Kuiper *et al.* (2022) affirm that the application of lean six-sigma may inadvertently reduce an organization's responsiveness to disruptions like a pandemic. Also, Kuiper *et al.* (2022) emphasize the value of agile methodologies in providing quick responses, and suggest that healthcare organizations should focus more on speed and flexibility to increase the resilience of operations, rather than solely on waste reduction and cost efficiency. In summary, for lean six-sigma to be effective, healthcare organizations must invest in leadership, training, and proper integration of these practices, which may justify the criticality indicated in this study.

Undoubtedly, the resilience capability of anticipation emerges as the most critical across all levels of the healthcare supply chain and practically all scenarios. This capability, which involves forecasting potential disruptions and preparing strategies in advance to mitigate their impacts, is identified as significantly lacking across healthcare providers, pharmaceutical distributors, and pharmaceutical producers. Enhancing this capability is not merely about risk management but also creating a proactive and agile healthcare supply chain capable of adapting to changes and challenges swiftly and effectively (Pettit *et al.,* 2013). The findings are supported by the study of Tortorella et al. (2023), which shows through their survey with 106 healthcare supply chain workers that resilience capabilities related to anticipation and monitoring (i.e., proactive capabilities) are less adopted than, for example, adaptability (reactive capability). Additionally, Alemsan *et al.* (2022) corroborate these findings, highlighting in their scoping review that anticipation is the resilience capability with the fewest studies within the healthcare supply chain context, further emphasizing the need for more focused research and implementation efforts in this area.

VSM is a practice widely adopted across all types of organizations and scenarios, with the exception of pharmaceutical distributors during high-probability events. The lack of criticality of this lean practice aligns with studies showing that VSM is the most commonly used technique for reducing costs and eliminating waste in the healthcare supply chain, according to the literature reviews by Khorasani *et al*. (2020) and Akmal (2020). In contrast to this work, Abideen and Mohamed (2020) demonstrate the successful application of VSM in a pharmaceutical distribution center and this indicates that healthcare organizations do not have a problem adopting VSM, and the lack of adoption by distributors could potentially be easily resolved with targeted interventions

5.5 FINAL CONSIDERATIONS

The objective of this phase was to analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios. The study was conducted as a case study within four Italian organizations: two healthcare providers, a pharmaceutical distributor, and a pharmaceutical producer, collectively representing the healthcare supply chain. Based on the work by Alemsan *et al*. (2022), a questionnaire was developed to evaluate the adoption level of lean practices and resilience capabilities, garnering a total of 100 responses. Also, experts evaluated the importance level of each lean practice e resilience capability in each of four disruptive scenarios. From these data, it was possible to identify the most critical lean practices and resilience capabilities for each disruptive scenario.

5.5.1 Theoretical Implications

Regarding theoretical implications, this research systematically identifies critical lean practices and resilience capabilities that are underutilized at various tier levels within the healthcare supply chain. The study highlights significant opportunities for theoretical advancement in operational efficiency and system robustness during disruptions. Additionally, the study introduces a novel methodological approach to evaluate the effectiveness of lean and resilience practices across different disruptive scenarios, thereby enriching the theoretical framework for crisis management within healthcare operations. Moreover, by identifying critical lean practices and resilience capabilities, this research guides further studies to explore these areas and understand their interrelationships across all levels of the healthcare supply chain. The study also underscores the importance and potential of cross-tier collaboration within healthcare supply chains, providing a theoretical basis for understanding how different tiers can interact more effectively to enhance overall performance.

5.5.2 Practical Contributions

The research provides practical contributions by highlighting the critical roles as JIT practice and anticipation capability in bolstering the performance of all the healthcare supply chain.. The study also introduces a scenario analysis framework, enabling organizations to assess and strategize against potential disruptions systematically. These insights not only aid in enhancing operational efficiency and resilience but also support the continuous delivery of high-quality patient care. Also, the study provides information to formulate strategies for guide managers to prioritize practices and capabilities in order to navigate disruptions towards more efficient supply chain operations . Furthermore, the study enables a systemic view of the healthcare supply chain, encouraging an understanding of how each organization contributes to the whole supply chain, rather than focusing solely on individual organizational performance.

5.5.3 Limitations and Future Research

It is important to acknowledge some limitations of this study. The case study was conducted within the context of the Italian healthcare supply chain, limiting the generalizability of the findings to other countries and healthcare systems. Future studies could address these geographical disparities to enhance the robustness of the theoretical and practical applications suggested. The focus on a single value stream and the sample size also present limitations. To mitigate these limitations, future research should consider expanding the scope of investigation to include multiple value streams and analyse more healthcare organizations. Additionally, the analysis of disruptive scenarios, while comprehensive, is constrained by the subjective assessment of probability and consequence, which could vary significantly in real-world situations. Future studies could adopt quantitative assessment models that use statistical or mathematical formulations to estimate the likelihood and potential impacts of disruptions as Monte Carlo simulations or Bayesian networks.

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APPENDIX A – QUESTIONNAIRE

I. Profile
What position/role do you hold in your organization? ____________
How long have you been in this role within the organization? ____________
What department do you work in within your organization? ____________
How much experience do you have with Lean Implementation? ____________

II. Lean
What is the level of adoption of the following Lean practices within your organization?
1 - It has never been used in my organization
2 - It has been used in the past in my organization
3 - It is currently used in a department of the organization
4 - It is currently used in more than one department of the organization
5 - It is currently used practically throughout the organization

VSM _____
Visual management _____
A3 _____
Standardized work _____
Pull System _____
Kanban _____
5S _____
Departmental Layout _____
VMI _____
Inventory Management _____
Spaghetti diagram _____
Just-in-time _____
Continuous Improvement _____
Kaizen. _____
RFID _____
Autonomation _____
Six-sigma _____
Poka-yoke _____

III. Resilience
What is the level of development of the following Resilience Capabilities in your organization?
1 - Undeveloped
2 - Underdeveloped
3 - Reasonably developed
4 - Developed
5 - Very developed

Flexibility _____
Capacity _____
Efficiency _____
Visibility _____
Adaptability _____
Anticipation _____
Recovery _____
Dispersion _____
Collaboration _____
Organization _____
Market position _____
Security/ Safety _____
Financial Strength. _____

6 RESULTS

This chapter presents the compiled results from the three articles that comprise this thesis. First, in Article 1, a scoping review was conducted and selected 44 articles. The descriptive analysis identified the distribution of articles by year, journal, and author. It is evident that this is an emerging topic whose interest has been growing over the last few years, with its peak of publications occurring in 2019. Regarding the main journals that have been publishing on this topic, eight stood out with at least two publications each. The remaining works were scattered across another 25 journals. It is worth noting the interdisciplinary nature of these journals, as there is a combination of journals from different fields, such as operations management, safety, ergonomics, and healthcare. In addition, 159 authors contributed to the works consolidated in the corpus, and seven of them appeared in two publications each. Also, the frequency of publications according to the tier levels of the healthcare supply chain was analyzed. 76% of the articles studied only one tier level, and the remaining 24% focused on two different tier levels. No work has approached the entire healthcare supply chain.

The content analysis showed the resilience capabilities which were benefit from the integration of lean practices in the healthcare supply chain. More than half of the articles related lean practices to three resilience capabilities: efficiency, visibility, and collaboration. In opposition, the resilience capability market position was the least emphasized by the lean practices. Regarding the distribution of lean practices, the most frequently applied are VSM and standardized work, with more studies focusing on distributors and healthcare providers. The most frequently studied healthcare value stream in terms of lean implementation was medical consumables, with 16 citations. On the other hand, medical equipment and information were the value streams with the lowest number of citations.

The relationship between lean practices and resilience capabilities was analyzed by a relevance analysis, resulting in 234 pairwise relationships. Of these, 16 (7%) resulted in highly relevant relationships, 83 (35%) were of moderate relevance, and 146 (58%) were classified as lowly relevant. Highly relevant relationships imply that lean practices are quite likely to support the development of resilience capabilities in the healthcare supply chain. Lean practices such as inventory management and VSM stood out with multiple highly relevant relationships with resilience capabilities. The most relevant resilience capabilities included efficiency, visibility, collaboration, and security/safety. In terms of resilience capabilities, efficiency had the highest number of highly relevant pairwise relationships and no lowly relevant relationship with any lean practice. Moderately relevant relationships suggest that lean practices and resilience capabilities are compatible but may require certain adaptations. This need was more prominent with practices like 5S and RFID, which showed moderate relevance with various resilience capabilities such as flexibility, capacity, efficiency, visibility, collaboration, and security/safety. Flexibility was found moderately related to multiple lean practices. Lowly relevant relationships indicate that significant modifications are needed to make these associations viable. The spaghetti diagram had the highest number of lowly relevant relationships. Despite its benefits, it is not widely used in the healthcare supply chain. Resilience capabilities like anticipation, recovery, and market position had lowly relevant relationships with all lean practices.

The relationships between lean practices and resilience capabilities were summarized across different healthcare value streams at each tier level of the healthcare supply chain in a framework. For developing resilience capabilities of healthcare supply chain agents from tier level 1, the most important lean practices appear to be inventory management, continuous improvement, and kanban. These practices are likely to influence the improvement of visibility, efficiency, and security/safety. The drugs value stream seemed to be the most benefited one. At tier level 2, the standout lean practices were VSM, inventory management, JIT, and 5S. The adoption of these practices may be highly important for developing resilience capabilities like efficiency, visibility, and collaboration, with a particular emphasis on the medical consumables value stream. At tier level 3, VSM, standardized work, and 5S appeared to be particularly relevant for enhancing the resilience capability of the patient value stream, positively affecting efficiency, visibility, and collaboration.

Based on the results from Phase 1, it can be observed that there is theoretical evidence about the relationship between lean practices and resilience in the healthcare sector. However, it is necessary to validate this relationship empirically. To achieve this, a survey was conducted on Article 2 with 123 healthcare supply chain employees to understand the relationship between lean principles adoption and resilience development. Two hypotheses were formulated: H1: The adoption of lean principles positively impacts resilience development in the healthcare supply chain. H2:

Resilience development positively mediates the effect of lean principles adoption on operational performance in the healthcare supply chain.

For data analysis, a set of Ordinary Least Square (OLS) hierarchical linear regression models was carried out to test three models. Model 1: Regression with resilience development (dependent variable) and lean principles adoption (independent variable). Model 2: Regression with operational performance (dependent variable) and lean principles adoption (independent variable). Model 3: Operational performance regressed on both the independent variable (lean principles adoption) and the mediating variable (resilience development). Furthermore, two contextual characteristics were added as control variables: tier level and company size.

The first model showed that the resilience development construct was significantly and positively associated with the lean principles adoption construct, with an adjusted R^2 of 0.170. These findings suggest that when healthcare supply chains adopt lean principles, their resilience development is likely to be improved, supporting hypothesis H1. The second model indicated that the adoption of lean principles is positively associated with operational performance, explaining 24.6% of its variation. However, when the resilience development construct is included in the regression analysis (Model 3), there is a significant increase in the ability to predict operational performance variation. This indicates that although lean principles adoption has a positive direct effect (Model 2), including the indirect effects through the development of resilience (mediating effect) significantly improves operational performance (Model 3). These findings support hypothesis H2.

Regarding the control variables, company size had no significant effect on any of the models, indicating there is no significant relationship between company size and resilience, and company size and operational performance. In contrast, the Tier Level control variable had a significant but negative effect on operational performance. This means that the further upstream in the supply chain (away from the end customer), the greater the operational performance improvement score. The closer to the end customer, the lower the operational performance improvement score

Since the relationship has been empirically validated, it is crucial to explore its application in real-world scenarios. In this way, In the third phase, a case study was conducted in the Italian healthcare supply chain to analyze how lean practices and resilience capabilities are developed in practice according to different disruptive scenarios. Four organizations were analyzed: two healthcare providers, a pharmaceutical distributor, and a pharmaceutical producer. Four disruptive scenarios were considered: low and high event consequence, and low and high event probability of occurrence. Additionally, eight experts on lean healthcare supply chains rated the level of importance for each practice and capability in each of the four scenarios. Based on questionnaires completed by 100 employees of these organizations, the level of criticality was calculated and the most critical lean practices and resilience capabilities for each organization and each scenario were identified. Criticality is related to low adoption and high importance given by the experts.

For the Pharmaceutical Producer, poka-yoke, A3, and JIT were critical across all scenarios, highlighting the need to bolster quality control, problem-solving capabilities, and operational efficiency. Anticipation and recovery were critical in low-probability scenarios, indicating a lack of preparedness for rare events. For the Pharmaceutical Distributor, the identification of JIT as a critical practice highlights a significant operational gap. A3 was critical in high-probability scenarios, underscoring the need for structured problem-solving approaches. The 5S practice was highlighted in multiple scenarios, emphasizing its crucial but underdeveloped role. Anticipation capability was critical in all scenarios, pointing to a strategic gap in current preparedness efforts. For Healthcare Provider A, the analysis of lean practices and resilience capabilities across various disruptive scenarios revealed key insights. Lean Six Sigma and poka-yoke practices emerged consistently across all scenarios. Kaizen practice is prominent in low-consequence scenarios, while VMI, RFID, and autonomation are critical in high-consequence scenarios. Anticipation and recovery capabilities were consistently present in more complex scenarios. For Healthcare Provider B, the consistently underutilized roles of kanban and JIT practices were noted across all scenarios. Anticipation capability was consistently identified as both critical and underdeveloped in all disruption scenarios.

In broad analysis, it becomes apparent that JIT practice, with the exception of Healthcare Provider A, is significantly underutilized across the healthcare supply chain. Lean Six Sigma practice is critical in at least two scenarios for healthcare providers and the pharmaceutical distributor but not for the pharmaceutical producer, who consistently invests in Six Sigma training and projects. The resilience capability of anticipation emerges as the most critical across all levels of the healthcare supply chain and practically all scenarios. This capability involves forecasting potential disruptions and preparing strategies to mitigate their impacts. It is significantly lacking across healthcare providers, pharmaceutical distributors, and pharmaceutical producers.

Table 18 presents an analysis of the relationships between the variables studied in this thesis. The table systematically illustrates the interconnections among lean practices, resilience, tier levels, value streams, operational performance, and disruptive scenarios. Each intersection marked with an "x" represents a relationship addressed by this study. This structured representation provides a clear overview serving as a foundation for further studies.

Table 18 - Analysis of the Relationships between Variables Studied in the Thesis

	Lean	Resilience	Tier Level	Value Stream	Operational Performance	Disruptive Scenarios
Lean	-	x	x	x	x	x
Resilience	x	-	x	-	x	x
Tier Level	x	x	-	x	x	x
Value Stream	x	-	x	-	-	-
Operational Performance	x	x	x	-	-	-
Disruptive Scenarios	x	x	x	-	-	-

A brief explanation follows on how each pair of relationships was addressed. *Lean and Resilience:* A scoping review was conducted to map the relationship between lean practices and resilience capabilities in the healthcare supply chain. Tested models showed that the adoption of lean principles influences the development of resilience, and this development mediates the relationship between the adoption of lean principles and operational performance. This demonstrates that resilience is a critical factor for maximizing the benefits of lean practices in the healthcare supply chain. *Lean and Tier Level:* Through the scoping review, a distribution of lean practices across the three levels of the healthcare supply chain was made. VSM practice was the most studied for tier level 2 and 3, while Inventory Management was the most studied for tier level

1. Also, It was noted that studies usually work with lean adoption individually, and no study analyzed all the three tier levels of the healthcare supply chain comprehensively. Additionally, in the case study, critical lean practices were defined for each tier level. *Lean and Value Stream:* The scoping review mapped the application of lean practices in different value streams of the healthcare supply chain, with the medical consumables flow being the most explored and the information flow being the least explored by the articles.

Lean and Operational Performance: The adoption of lean principles in the healthcare supply chain significantly improves operational performance. This includes improvements in productivity, cost efficiency, clinical quality, patient and staff safety, and financial results. Lean principles help reduce waste, standardize processes, and create a continuous flow, leading to better overall performance. *Lean and Disruptive Scenarios:* An analysis with lean supply chain experts identified the importance of each lean practice for various disruptive scenarios. For example, RFID had the lowest importance value for low probability and low consequence scenarios, while Inventory Management and JIT received the highest importance scores for high consequence scenarios.

Resilience and Tier Level: Through the framework from phase 1, the main resilience capabilities for each tier level were identified. Efficiency and visibility were recognized as the two main capabilities for all tier levels of the supply chain. Additionally, in the case study, the most critical practices for each tier level were identified, with the anticipation capability being present at all tier levels. *Resilience and Operational Performance:* This relationship was supported by the empirical results presented in the thesis. The development of resilience positively mediates the relationship between the lean principles adoption and operational performance. Resilience helps mitigate the impacts of disruptive events, maintaining operational continuity and efficiency. *Resilience and Disruptive Scenarios:* An analysis with experts identified the importance of each resilience capability for various disruptive scenarios. For example, Market Position had the lowest value for low probability and low consequence scenarios, while flexibility, anticipation, and recovery received the highest scores for high consequence scenarios.

Tier Level and Value Stream: From the framework in phase 1, the main value streams for each tier level were identified. For the most distant tier, the main value stream was drugs; for the middle tier, it was medical consumables; and for the downstream tier, it was patients. *Tier Level and Disruptive Scenarios:* In the case study, lean practices and resilience capabilities were distributed for each tier level and for disruptive scenarios. In this thesis, no direct relationships were identified between resilience capabilities and value streams, tier levels and operational performance, value streams and operational performance, value streams and disruptive scenarios, or operational performance and disruptive scenarios.

7 CONCLUSIONS

This section aims to demonstrate how the research questions were answered and how the specific objectives and the general objective were achieved. Additionally, the limitations of the work and suggestions for future studies will be presented.

The first research question, which is "What is the relationship between lean practices and resilience capabilities in the healthcare supply chain?" was answered through a comprehensive scoping review of the existing literature. By analyzing 44 articles from various databases, the study identified key lean practices and resilience capabilities and established their interrelationships. The review revealed that lean practices, such as VSM, visual management, standardized work, and inventory management, significantly contribute to resilience capabilities, including efficiency, visibility, and collaboration. These relationships were identified pairwise and ranked by their level of relevance. The relevance level was based on three factors: the frequency of citation, the pervasiveness of lean practices across different tiers of the healthcare supply chain, and their application across various healthcare value streams. This process highlighted the most critical lean practices for enhancing specific resilience capabilities. Additionally, a framework was developed, distributing the main lean practices, key resilience capabilities, and principal value streams for each tier level of the healthcare supply chain. Therefore, the first specific objective, which is to identify the relationship between lean practices and resilience capabilities in the healthcare supply chain, was achieved.

The second research question, which is "How does resilience development influence the association between lean principles adoption and operational performance in the healthcare supply chain?", was addressed through a survey conducted among healthcare supply chain professionals in Brazil. The survey data were analyzed using statistical methods to test the hypothesized relationships. The results demonstrated that resilience development positively influences the association between lean principles adoption and operational performance. Specifically, the implementation of lean principles, facilitated by resilience, leads to improved operational performance by minimizing disruptions and ensuring continuity in healthcare services. This finding highlights the importance of resilience development as a critical factor in maximizing the benefits of lean adoption. Therefore, the second specific objective, which is to examine the mediating role of resilience development on the association between lean principles adoption and operational performance in the healthcare supply chain, was achieved.

The third research question was "How does the deployment of lean practices and resilience capabilities vary within the healthcare supply chain across different disruptive scenarios?" and it was addressed through a case study conducted in the Italian healthcare supply chain. The case study examined how specific lean practices and resilience capabilities were deployed across various disruptive scenarios. The findings indicated that practices such as JIT and anticipation capability are critical across different disruptive events. The designation of "critical" indicates that these practices are considered essential by specialists but are not widely adopted, pointing to a gap between their recognized importance and their actual implementation. The case study also revealed that the effectiveness of lean practices and resilience capabilities varies depending on the nature and severity of the disruptions, emphasizing the need for a custom approach in different scenarios. Therefore, the third specific objective, which is to analyze the deployment of lean practices and resilience capabilities within the healthcare supply chain across different disruptive scenarios, was achieved.

The general objective of this work is to investigate the integration of lean management and resilience within the healthcare supply chain. This objective was achieved through a comprehensive research approach that included a scoping review, survey, and case study. The scoping review identified key lean practices and resilience capabilities and established their interrelationships, providing a theoretical framework for understanding how these concepts can be integrated. The survey empirically validated the mediating role of resilience in enhancing operational performance through lean adoption, and the case study demonstrated how these practices and capabilities are deployed across different disruptive scenarios. Together, these methodologies provided a robust analysis that meets the general objective by highlighting the complementary nature of lean and resilience in the healthcare supply chain.

This thesis advances theoretical understanding by integrating two approaches often seen as oppositional: lean and resilience within the healthcare supply chain. Through a robust methodology that includes a scoping review, survey, and case study, the research reveals how lean and resilience can be complementary. The work proposes a theoretical framework mapping the main lean practices and resilience capabilities, providing a new perspective. Additionally, it empirically validates key hypotheses about the mediation of resilience in the relationship between lean adoption and operational performance, contributing to the literature by showing that integrating these approaches can lead to significant improvements in operational performance. Finally, the work introduces a novel approach to evaluate the lean and resilience across different disruptive scenarios.

From a practical perspective, this thesis is a valuable tool for healthcare managers seeking to implement lean practices without compromising resilience. The research identifies key lean practices that can be prioritized to build resilience. The case study and survey provide real-world examples and insights that managers can use to make informed decisions. This practical guidance is essential for improving the operational performance of healthcare supply chains, ensuring they are better equipped to handle disruptions and continue providing high-quality care to patients. Additionally, it emphasizes the necessity of understanding the entire supply chain rather than focusing solely on individual organizations, promoting a holistic approach to supply chain management.

Some limitations of the work can be highlighted. The scoping review used five databases, which might have excluded relevant articles. The study relied on a single approach for evaluating resilience, which may not encompass the full range of perspectives and interpretations found in the broader literature. The sample size for the survey, restricted to healthcare supply chain professionals in Brazil, and the case study confined to Italian healthcare organizations, might not capture the full diversity of practices and challenges across different contexts. The healthcare supply chain was classified into only three levels, which may not reflect all sector complexities. Additionally, the study was limited to four organizations, which might not be representative of the entire sector.

There are some suggestions for future work. Firstly, to conduct comparative studies in different countries and regions to understand how cultural and policy variations impact the integration of lean practices and resilience capabilities in the healthcare supply chain. Also, to investigate the long-term impacts of adopting lean practices and resilience capabilities on the operational performance of healthcare supply chains. In addition, to examine the role of other paradigms as Industry 4.0 and Green practices in enhancing the integration of lean practices and resilience capabilities in the healthcare supply chain. Furthermore, to perform interviews and focus groups with healthcare supply chain professionals to deepen the understanding of their perceptions and experiences in implementing lean and resilience. Moreover, to extend the investigation to cover additional value streams within the healthcare supply chain. Finally, it is recommended to explore the relationships between variables that were not directly examined in this thesis, such as the relationship between resilience and value streams, tier levels and operational performance, operational performance and disruptive scenarios in the context of lean healthcare supply chain.