A framework for assessing the resilience of after-sales service supply chains in the medical equipment industry

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A framework for assessing the resilience of after-sales service supply chains in the medical equipment industry

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Preface

Dear readers,

This document reports on my thesis project, my final challenge to complete my Master's degree in Complex Systems Engineering and Management. Before coming to Delft to study, I worked as an intern in a medical equipment company for a few months, which gave me experience in the after-sales service supply chain of medical equipment and provided a good basis for the completion of my thesis. During my internship, I learned about the characteristics of the medical equipment after-sales service supply chain and the serious consequences of supply chain disruptions. Therefore, this thesis attempts to address these issues and reduce the impact of disruptions by improving supply chain resilience.

I have encountered many problems during the completion of my thesis, and I would like to thank all the people who helped me. First of all, I would like to thank my supervisors, Pieter and Stefano. For special reasons, I needed to finish my thesis on time, and my supervisors helped me a lot with this. We had regular meetings every week, and my supervisors were able to give me timely guidance and make timely adjustments to my progress according to my progress of completion. So, I am very grateful for the timely feedback I received from my supervisors. In addition, I would like to thank all the professionals who participated in my interviews. The geographical scope of the research for the thesis is medical device companies in China. Since I have been studying in the Netherlands, all interviews had to be conducted online, so I thank all participants for their cooperation and understanding. Finally, I would like to thank my parents who are my strongest backing. When I was under a lot of stress to finish my thesis, they were the ones who gave me heart relief and timely help. Because of their help, I was able to finish my thesis project in a healthy state.

After completing this thesis, my student life will be over. I am very happy to be able to complete my master's program at TU Delft. The learning experience at TU Delft was different from the previous educational experiences I received, it was an interesting, intensive, and educational process that impressed me and helped me to become a better person. Now new and exciting challenges are on the horizon.

Y. Bing
Delft, August 2021

Summary

As the complexity of global supply chains increases, so does the turbulence and disruption they are suffering from. The medical equipment after-sales service supply chain is closely related to the healthcare industry. Therefore, the ability to provide high levels of customer satisfaction with after-sales services affects not only the performance of the medical equipment companies but also the lives and health of patients. This motivated us to study supply chain resilience in order to help managers in the medical equipment industry improve the resilience of after-sales service supply chains.

Supply chain resilience is defined as "The capacity of a supply chain to prepare for, respond to, and recover from disturbances such that afterwards it reaches a positive steady state operation in an acceptable cost and time." Through literature research, we found that there is no research specifically on the resilience of the after-sales service supply chain of medical equipment. To fill this gap, we formulated the main research question for this thesis as: *"How to assess the resilience of the after-sales service supply chain in the medical equipment industry?"*. To answer this research question, we have designed a supply chain resilience framework to help managers assess the resilience of medical equipment after-sales service supply chains. This conceptual framework identifies enablers and vulnerabilities, and provides observable indicators for each of these elements. We expect that this will help managers to better deal with turbulence and disruptions. Based on the identified knowledge gaps and the main research question, we opted for a mixed-method approach in two phases:

1. *Framework development:* We identified and synthesize the elements of existing supply chain resilience frameworks found through literature research into a single resilience framework applicable to the after-sales services supply chain for medical equipment. This framework identifies the enablers that need to be maximized and the vulnerabilities that need to be minimized to enhance supply chain resilience and operationalizes these elements as observable indicators.
2. *Framework validation:* Considering the strong growth of the medical equipment market in China, and the Chinese government ambition to provide safe, effective, convenient, and affordable healthcare services to both rural and urban residents by 2020, we have validated the proposed framework by interviewing professionals working in medical equipment companies located in China. We used questionnaires and semi-structured interviews to determine how participants perceived the importance of the identified elements and indicators.

The resulting framework identifies 11 enablers and 5 vulnerabilities, operationalized by 43 indicators as summarized in the following two tables (Table 2 see next page).

Table 1 Vulnerabilities and indicators

Vulnerabilities	Indicators
Supplier disruptions	Frequency of occurrence per type of event
	Level of the supplier reliability
	Number of suppliers per type of goods
Organizational Complexity	Number of the hierarchical layer of the organizational chart.
	Number of the decision makers involved in a project
	Number of the processes and rules
External pressures	Product sales volume
	Monitoring the political events
	Price fluctuations
Transportation efficiency	Degree of optimization of transportation routes
	Time of customs inspection
	Transport capacity of the carrier
	Number of the delayed transportation orders
Turbulence	(No indicators)

Table 2 Enablers and indicators

Enablers	Indicators
Collaboration	Degree of familiarity with partners
	Efficiency of communication
Visibility	Level of information technology
	Degree of information exchange
	Ease of acquiring the information
Sharing information	Accuracy of forecast
	Accuracy of information
	Probability of uncertainty
Trust	Time that the relationship lasts between the buyer or the seller
	Confidential information sharing
	Existence of mutually beneficial cooperation terms
Risk management culture	Incentive and punishment of risk management
	Level of knowledge of risk management
	Risk management culture training
Leadership	Number of resilience strategies or decisions
	Magnitude of supply chain resilience power
	Degree of leadership understanding of supply chain resilience
Redundancy	Stock turnover rate
	Warehouses and facilities spread
Innovation	Percentage of innovations adopted
	Number of supply chain innovations per year
Flexibility	Spare part-supplier rate
	Sufficiency of financial resources
	Rate of deliver on time
	Rate of on-time arrival
Agility	Time to respond
	Time to access relevant data
	Time to detect threats
Adaptability	Speed of re-routing the requirements
	Learning from experience

As the proposed supply chain resilience framework has not been tested empirically by applying it within a medical equipment company, a first recommendation is to perform such tests. By analysing and summarizing the results of the actual application, the framework can be improved further. Moreover, the expert validation was limited due to research time constraints. The reasons why participants considered some enablers and vulnerabilities to be unimportant could be investigated further, and the indicators can still be operationalized further. Finally, the relative importance of enablers and vulnerabilities could be investigated by using a multi-criteria decision-making method, so as to help managers select only the more important elements to improve the resilience of their supply chain.

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1 Introduction

1.1. Problem statement

The global medical equipment market has been increasing in the last years (Ramakrishna, Tian et al. 2015). An important component of this market is the after-sales services. These services provide spare parts, maintenance and repair service, online fault diagnosis, etc. In particular, the spare parts supply for repairing medical equipment is a very delicate part that requires attention to guarantee the required high service level. As Knapp (2019) claimed, the after-sales service is of high importance for medium-sized medical technology companies. Therefore, a continuous and reliable after-sale service supply chain is crucial to ensure the workability of the equipment.

The after-sales service medical equipment supply chain is not able to make forecasts of demand, which are usually estimated based on historical data. Because it is very difficult to forecast after-sales spare parts. Sometimes, the demand for spare parts can be so much higher than estimated that they cannot be supplied on time. In addition, for the after-sales service supply chain for medical equipment, customer satisfaction is very important, so on-time arrival is critical. For example, the recent COVID-19 pandemic highlighted several supply chain deficiencies that needed to be addressed during the next emergency or peak period. In particular, manufacturers struggled to provide responsive service to maintain or repair medical equipment. This was due to several reasons. First, spare parts are not always in stock, as medical equipment companies try to keep inventories low, due to the lean strategies these companies plan to adopt to get low inventory costs. Secondly, during the COVID-19 pandemic, supplier lead times were extended from days to weeks, and even from weeks to months for some products, due to factory closures. This disrupted the ordering plan for medical equipment spare parts. Third, shipping delays and customs inspections also affected the timeliness of the supply chain. However, maintaining a high level of inventory is not an easy solution. What should be improved is the relationship between manufacturer and customer, communication, and responsiveness of the after-sales department (Hanna, Skipper et al. 2010). Establishing supply chain information sharing mechanisms with collaborators, including customers and suppliers, can help companies cope with external shocks (Sarkar and Kumar 2015, Wang, Wang et al. 2019). In addition, organizational changes in the medical equipment supply chain can improve the responsiveness of the organization.

In this changing environment, the medical equipment after-sales service supply chain is now more susceptible to disruptions, which can have a serious impact on medical equipment companies and even hospitals in the event of a supply chain disruption. Therefore, addressing supply chain resilience is considered to be the key to sustainable supply chain advantage. This study will address the above discussed problem by improving supply chain resilience. Pires Ribeiro and Barbosa-Povoa (2018) proposed a comprehensive and simple definition of supply chain resilience through a literature review:

“A resilient the capacity of a supply chain should be able to prepare for, respond to, and recover from disturbances and such that afterward maintain it reaches a positive steady-state operation in an acceptable cost and time.”

Jafarnejad, Momeni et al. (2019) have studied the supply chain resilience of medical equipment. This literature explores the enablers of the medical equipment supply chain using the hesitant fuzzy Delphi method. Some suggestions for future research are also made, for example, researchers can use multi-criteria decision-making techniques such as hierarchical analysis and PROMETHEE in their future studies to rank the resilience enablers in the supply chain. It is also suggested to use the Interpretive Structural Model (ISM) approach to identify the relationship between enablers. Based on the suggestions made in this paper, this research can explore the resilience enablers focusing on the after-sales service supply chain of medical equipment and investigate the importance of resilience enablers. But in the research, instead of using the suggested method, we used the questionnaire method.

In addition, Stone and Rahimifard (2018) proposed a resilience framework for agri-food supply chains. The findings suggest that the complexity of agri-food supply chains and subsequent exposure to almost constant external disruptions means that disruptions cannot be considered as one-off events; therefore, resilience must focus on the ability to not only maintain core functions but also adapt to changing conditions. The research ideas in this literature provide insight for our research to improve supply chain resilience by designing a resilience framework adapted to medical equipment after-sales service supply chains.

1.2. Research objective

The objective of this project is to propose a supply chain resilience framework specifically for the medical equipment industry. The idea is that by using the designed supply chain resilience framework, the after-sales service supply chain resilience of the medical equipment industry can be enhanced such that the after-sales service supply chain in the medical equipment industry can respond to problems in a timely manner and improve the problem of decreasing customer satisfaction caused by supply chain disruptions. This thesis thus should help improve the continuity of the supply chain for medical equipment spare parts by appropriately increasing the supply chain elasticity, reducing supply disruptions, and adapting to the fluctuating demand in the medical equipment industry. In this thesis project, a mixed-method approach was used to address the research questions. The first research phase is based on an extensive literature study and the characteristics of the medical equipment industry to design the framework used to enhance supply chain resilience. In the second phase, the data collected through interviews can further help to validate the framework design.

This study focuses on after-sales service supply chain resilience in the medical device industry. After-sales service provides maintenance, repair (including remote maintenance services), and spare parts supply. More specifically, this project will focus on the supply chain of medical equipment spare parts for the after-sales service sector. The geographical focus of this thesis study is in China. The medical equipment market in China has grown considerably. In addition, many famous medical equipment companies have established their companies or subsidiaries in China, such as Shanghai Siemens Medical Equipment Co. and Johnson & Johnson (China) Medical Equipment Co. Meanwhile, the Chinese government has initiated healthcare reforms in a quest to develop a new system to provide "safe, effective, convenient, and affordable" healthcare services to both rural and urban residents by 2020 (Wang 2018). Thus, China has a broader perspective and an urgent need to develop healthcare reform. Therefore, limiting research in China is of more practical importance.

1.3. Knowledge gap and added value of research

1.3.1. Knowledge gap

By studying the literature on the current state of research on the supply chain of the medical equipment industry, we found that although there is literature on the medical equipment supply chain, there is no research on the after-sales service supply chain of the medical equipment industry. When searching the literature on medical equipment supply chains, most of the papers given in the search results are about supply chains in the healthcare industry (Aldrighetti, Zennaro et al. 2019, Marques, Martins et al. 2020, Senna, Reis et al. 2020). The healthcare supply chain is a very unique segment because its main goal is to save lives rather than profits (Senna, Reis et al. 2020). The major participants in the healthcare supply chain include manufacturers (pharmaceuticals, medical equipment, and hospital medical supplies), distributors, healthcare providers, medical groups, insurance companies, government agencies, employers, government regulators, and users of healthcare services. As a result, some of the literature on supply chains in the healthcare industry involves research on the supply chain of medical equipment. Although the amount of literature on supply chain studies of medical equipment is not large, it still contributes to the diversity of medical equipment supply chain studies. For example, Ma, Gong et al. (2019) examined supply chain contracts in the medical device industry. The results of the literature search presented in Chapter 2 indicate that despite the diverse focus of research related to the medical equipment supply chain, there is a lack of research that focuses on the after-sales service supply chain in the medical equipment industry.

In addition to the practical objectives in the previous section, this thesis aims to fill the knowledge gap. As globalization exposes supply chains to various disruptions, there is a growing interest in the study of supply chain resilience. The purpose of this thesis is to assess after-sales service supply chain resilience in the medical equipment industry, which will be achieved through a resilience framework. A review of the literature reveals that there have been many studies on supply chain resilience frameworks. Some of these supply chain resilience frameworks have been designed based on specific industry contexts. These studies on supply chain resilience frameworks have covered the food and beverage industry (Purvis, Spall et al. 2016), automotive industry (Nikookar, Takala et al. 2014, Siva Kumar and Anbanandam 2020) and pharmaceutical industry (Aigbogun, Ghazali et al. 2014). All the literature has helped different industries to explore supply chain resilience and propose to have a targeted supply chain resilience framework. The results of the literature search presented in Chapter 2 show that although there have been many designs and studies on resilient supply chain frameworks, there is still a gap in research on resilience frameworks for after-sales service supply chains in the medical equipment industry.

1.3.2. Main research question

Customer after-sales service is a very important component of a medical device company, including diagnosis, repair, and maintenance of medical equipment. This is because, without medical equipment, even ordinary medical activities would be difficult to perform. In addition, diagnostic equipment is very important in everyday medical diagnosis, as 70 percent of medical decisions are based on the results of in vitro diagnostic tests (Connection 2021). If the equipment breaks down, medical decisions will be delayed, which will affect the patient's condition. Therefore, it is important for the customer as well as the patient to have the after-sales service equipment needed by the customer in a timely manner. Therefore, this thesis project will research the after-sales service supply chain in the medical equipment industry. In addition, the COVID-19 outbreak disrupted production and logistics activities (Araz, Choi et al. 2020, Singh, Kumar et al. 2020). We found that the COVID-19 embargo has also impacted the medical equipment after-sales service supply chain, thus there is a need for research to help medical equipment companies improve their supply chain resilience. For these reasons, the main research question of this thesis is.

“How to assess the resilience of the after-sales service supply chain in the medical equipment industry?”

The above research question has the following additional scientific and practical values. Firstly, it can fill the gap of research on supply chain resilience in the medical equipment industry. Secondly, due to the special characteristics of medical equipment, it becomes very important to ensure the continuity of the after-sales service supply chain. Enhancing supply chain resilience in the medical equipment industry can reduce supply chain disruptions. This not only ensures profitability but also contributes to saving lives. Finally, this project will explore the design of a supply chain resilience framework for the after-sales service supply chain of medical equipment. This framework can help supply chain leaders identify factors that can be used to enhance supply chain resilience to strengthen supply chain resilience so that the supply chain can quickly recover from disruptions to a balanced state.

1.4. Research approach and sub-questions

Based on the identified knowledge gaps and the main research question, this project aims to explore the resilience of the after-sales service supply chain in the medical equipment industry by using the mixed method approach (Creswell 2012). The main reason for choosing a mixed method approach for this research is that it allows to first develop a conceptual framework using qualitative methods (Phase 1), and then test it by collecting feedback from professionals in the field (Phase 2).

Based on the research on the conceptual validity of the framework by (Barreteau, Bots et al. 2010), we consider the design of a framework for supply chain resilience as a cyclic process. This cyclic process includes (1) Formulation of the research question; (2) Selecting the appropriate methods: Designing a framework for resilience in the medical equipment after-sales service supply chain context by mixed methods in order to enhance the resilience of the supply chain; (3) application of these methods to achieve results: by using interviews and questionnaires to test the resilience framework obtained in the first phase, thereby obtaining test results; (4) Reflecting on these results usually leads to new research questions:

reflecting on the test results and improving the resilience framework based on the reflections. In addition, the test results also lead to new research questions that can give recommendations for future research directions. Therefore, testing the resilience framework is an essential step in a cyclic process of research for the completion of the research process. The following section describes the specific research methods.

Phase 1 was to develop the supply chain resilient framework by using the qualitative method. In this first phase, literature research and observation were mainly used. Based on the context of the after-sales services supply chain for medical equipment, we synthesized the elements of existing supply chain resilience frameworks found through literature research into a single resilience framework applicable to the after-sales services supply chain for medical equipment. The framework identifies the enablers that need to be maximized and the vulnerabilities that need to be minimized to enhance supply chain resilience. Based on the identified enablers and vulnerabilities, we also operationalized the enablers and vulnerabilities by applying an observational approach to define indicators.

Phase 2 was to test the supply chain resilience framework proposed in the first phase, and was divided into three main parts:

1. Develop the questionnaire and interview questions to determine how professionals perceived the importance of the identified elements, and for what reasons, and how they perceived the usability of the measurement indicators. Then pre-test the questionnaire and interview questions for clarity and feasibility within given time limits, and improve them based on the findings and feedback obtained during the pre-test.
2. Conduct the questionnaire and interviews with professionals from Chinese medical equipment companies. Based on the answers of participants on the questionnaire, discuss with the participants whether the selected measurement indicators are applicable and reasonable in practice, and invite them to suggest additional measures that can be used in practice as measures of enablers and vulnerabilities.
3. Summarize the results based on the collected numerical and textual data, analyse the results and modify the supply chain resilience framework if necessary.

We opted for semi-structured interviews because they are considered to provide reliable and comparable qualitative data (Keller and Conradin 2020). Moreover, being more flexible in that the interviewer is allowed to adjust the interview questions based on feedback during the interview, the results in a more efficient interaction (Klandermans and Staggenborg 2002). Finally, to obtain feedback on our framework, we did not need confidential information within medical equipment companies. Therefore, we found the semi-structured interview method most suitable to test the supply chain resilient framework.

Based on the mixed-method approach, the following sub-research questions were constructed:

SQ1: What is the medical equipment industry after-sales service supply chain in the research?

SQ2: How is supply chain resilience conceptualized in the current literature?

SQ3: What are the enablers, vulnerabilities, and objectives in the supply chain resilience framework?

SQ4: What are suitable indicators for measuring the identified enablers and vulnerabilities?

Each of the formulated sub-questions in the previous section requires a specific (set of) method(s) and data. The detailed research flow can be found in Figure 1.

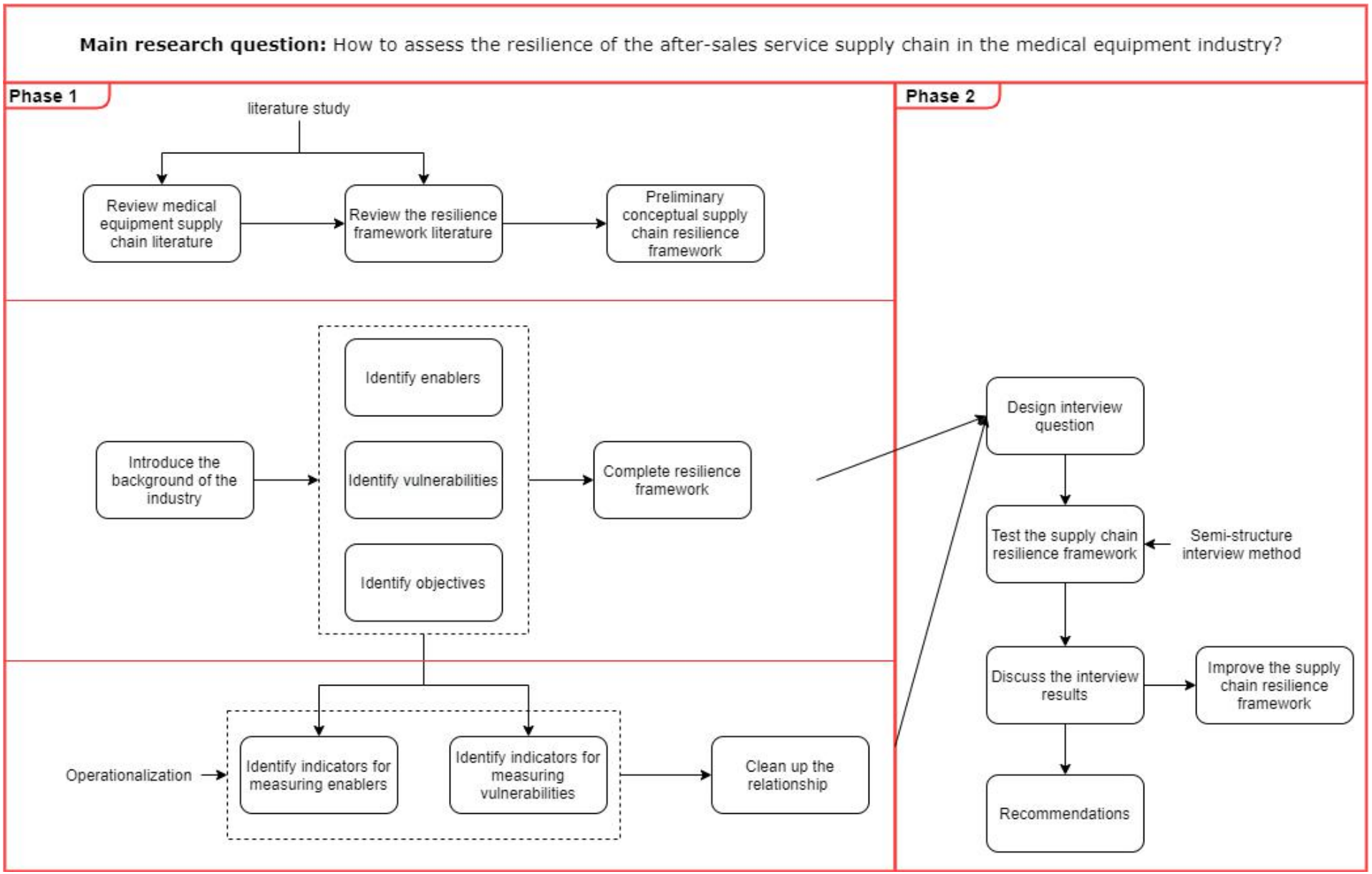

Figure 1 Research flow chart

1.5. Link to MSc CoSEM Program

The goal of the Complex System Engineering and Management (CoSEM) MSc program is to help students employ methods and tools for creatively designing technical solutions in organizations' engineering approaches. This project aims to provide a supply chain resilience framework to help the professional enhance the supply chain resilience. Therefore, this research into the field of supply chain resilience fits the Complex Systems Engineering and Management (CoSEM) master's program.

The thesis project also takes into account both public and business values. This analysis not only has a positive impact on society – saving lives but also improves the performance of the supply chain. Enhancing the resilience of the medical equipment after-sales service supply chain can reduce the impact of supply chain disruptions and allow customers to reapply medical equipment in the shortest possible time for timely patient care. In addition, high customer satisfaction is always the goal of the medical equipment after-sales service supply chain, which can achieve business value by improving customer satisfaction. In addition, in the thesis, data needs to be collected through interviews, which is an important aspect faced in the course of the Course (SEN1121). Finally, this is also a thesis project that requires consideration of multi-actors, suppliers, customers, and the medical equipment company itself, which is related to the main content of the coursework (SEN1141).

In summary, this research is firmly linked to the objectives of the master's programme Complex Systems Engineering and Management and is in line with the mission statement of the faculty.

1.6. Structure of this report

Chapter 2 of this thesis reports on the literature review, which aims to 1) identify the academic knowledge gaps described in Section 1.3; and 2) prepare for the design of the resilience framework. The rest of this report follows the structure in the research flow diagram in Figure 1. Hence, in Chapter 3, the enablers, vulnerabilities, and objectives in the supply chain resilience framework are described in detail. Chapter 4 introduces the indicators used to measure the enablers and vulnerabilities of the resilience framework and briefly explores the relationship between enablers and vulnerabilities in the framework to make the framework clearer. Chapter 5 introduces the testing procedure for the Phase II part and shows the process and results of the pre-test in detail. Chapter 6 presents the testing process of the designed supply chain resilience framework and the test results. Chapter 7 discusses the results obtained by testing the supply chain resilience framework and improves the designed resilience framework. Finally, in Chapter 8, the results are summarized and the main research questions are explored. In addition, recommendations for further research are presented in Chapter 8.

2 Research background and literature review

The supply chain resilience framework designed in this project will serve as a tool for professionals in the medical equipment field to use. By using an operational resilience framework to help supply chain organizations diagnose and enhance their after-sales service supply chain resilience. The main objective of this research is to develop, refine, and test a conceptual framework based on the current supply chain resilience framework literature and the specific medical equipment after-sales supply chain context that will assist professionals in their practice. The literature review is used to identify the academic knowledge gaps described in Section 1.3, and 2) prepare for the design of the resilience framework. The literature review allows us to understand the current state of research on the after-sales service supply chain of medical equipment. and to explore whether there is any research on the resilience of the medical equipment after-sales supply chain. In addition, this section also organizes the current state of research on supply chain resilience framework to prepare for the design of resilience framework. By reviewing the supply chain resilience framework literature, we can clearly know the existing framework components and focus on the parts that are meaningful for this paper's framework research. By compiling these meaningful components, we can design a better and more professional framework that can be used to enhance the resilience of the medical equipment after-sales service supply chain.

2.1. Literature review method

The review for this analysis includes the literature published on supply chain applications in medical equipment and resilient supply chain framework. More specifically, a comprehensive search using a combination of a descriptor, the keywords are (1) Supply Chain resilience; (2) Medical Equipment; (3) Resilient supply chain framework; (4) After-sales service supply Chain; (5) qualitative analysis. All keywords of the review are combined by using the Boolean operators 'AND' and 'OR'. For searching the scientific literature, this paper used several search engines which are Scopus, Google Scholar, ScienceDirect, Emerald, IEEE Xplore, and Taylor & Francis.

To exhaust the search, title, abstract, keywords and text were searched for a match. Furthermore, the literature review uses the snowballing method to search for articles. There are several exclusion criteria for searching the literature. Firstly, the paper only used the scientific literature published in English. Secondly, the literature review excludes the literature are published in books or reports. Last, the literature on healthcare excludes the papers that focus on analysing the pharmaceutical supply chain.

2.2. Supply chain of medical equipment industry

The main contents of the selected literature are described in Table 3. There are a total of five papers on medical device supply chains in this section, but only one paper involves the study of supply chain resilience. This paper focuses on the topic of medical equipment resilience in an extended way, identifying the key factors affecting the resilience of medical equipment supply chains for the first time and simulating four scenarios and their impact on the system (Jafarnejad, Momeni et al. 2019). The rest of the literature is related to medical equipment supply chains. Hasani, Zegordi et al. (2015) studied the evaluation of a general supply chain network for medical equipment and developed an efficient memory algorithm to maximize the after-tax profit of a medical equipment closed-loop global supply chain network (GSCN) under budget uncertainty.

In addition, some scholars have explored the use of resilience management and information technology, or user participation in supply chain activities. Liao, Deng et al. (2019) found very limited literature on the current medical equipment supply chain development and proposed a framework for the first time to

evaluate the structure of medical equipment, the suppliers of raw materials or components, and the emerging technologies and manufacturing processes used to make the equipment. Allen, Xie et al. (2016) explored information and communication technologies (ICT) to manage the adoption and use of medical equipment in a reverse exchange (RE) system in which equipment is returned to the source for exchange. They found that ICT adoption and integration into critical operational processes increases with the perception of risks and value associated with medical equipment. Finally, the analysis revealed that although medical equipment supply chains have been studied in different topics, the existing literature lacks research on the resilience of medical equipment after-sales service supply chains.

Table 3 The overview of the medical equipment papers

Authors	Title	Description
Liao, Deng et al. (2019)	Proposing a Framework for Developing Supply Chains of Medical Devices	The research explores how the features of a medical device impact on the choice of its supply chain.
Jafarnejad, Momeni et al. (2019)	A dynamic supply chain resilience model for medical equipment's industry	The main focus of this paper is to broaden the topic of medical equipment resilience. This study identifies, for the first time, the key factors that influence the resilience of the medical equipment supply chain. In addition, four scenarios and their impact on the system are simulated.
Ma, Gong et al. (2019)	Quality efforts in medical supply chains considering patient benefits	This paper research the supply chain contract in the medical equipment Industry and focuses on the impact of a manufacturer's and a retailer's patient concern levels on optimal pricing and quality decisions in an SC consisting of a manufacturer facing quality effort-dependent demand and a retailer in the medical equipment industry. This paper is to investigate quality efforts for SC contract design in relation to patient concerns and to study SC contract design in the medical equipment industry.
Hasani, Zegordi et al. (2015)	Robust closed-loop global supply chain network design under uncertainty: the case of the medical device industry	This paper designed a comprehensive optimization model to maximize the after-tax profit of a closed-loop global supply chain for medical devices under uncertainty.
Allen, Xie et al. (2016)	An exploratory study of reverse exchange systems used for medical devices in the UK National Health Service (NHS)	This study aims to provide insights into the scale and use of information and communication technology (ICT) in managing medical devices in the National Health Service (NHS), with a focus on reverse exchange (RE) systems as a part of the broader reverse logistics (RL) systems, within which medical devices are returned and exchanged.

2.3. Literature review of the supply chain resilience framework

Table 4 describes the methodology, type of supply chain, and the main goal of the literature on the selected supply chain resilience framework. The table clearly shows 13 papers on supply chain resilience and finds that many industries have been studied on supply chain resilience framework currently. Nikookar, Takala et al. (2014) and Hecht, Biehl et al. (2019) did supply chain resilience studies in the food industry and the automotive industry using qualitative methods, respectively. Nikookar, Takala et al. (2014) identified and eliminated barriers affecting resilience by identifying the factors that may cause trouble in the near future. The theoretical framework was established to summarize the significant finding in the area of resilient supply chain and as a guideline for the empirical part. Hecht, Biehl et al. (2019) also identified the factors that may contribute to organization-level resilience by using qualitative method. This research is used to help food system organizations, researchers, and government officials identify priorities for investigating vulnerabilities in diverse operations and potential strategies to improve resilience in the face of ongoing and growing threats. Stone and Rahimifard (2018)studied the principles of agri-food supply chains to propose a rigorous and food-specific resilience framework with a primary focus on end-consumer food security, using a broader understanding of resilience from different research areas. In addition, Aigbogun, Ghazali et al. (2014) examined a supply chain resilience framework in the pharmaceutical field.

In addition, some frameworks have been used to analyse various capabilities. Purvis, Spall et al. (2016) proposed a framework for the development and implementation of a resilient supply chain strategy, which illustrates the relevance of various management paradigms (robustness, agility, leanness, and flexibility) in increasing a company's ability to deal with disturbances emerging from its supply chain. Gunasekaran, Subramanian et al. (2015) proposed global sourcing (GS) resilience framework to analyse the impact of GS complexity factors on supply chain resilience. Siva Kumar and Anbanandam (2020) proposed a "situation–actor–process–learning–action–performance" (SAP–LAP) framework which showed that the efficacy and simplicity of the SAP–LAP framework may enable SC stakeholders to initiate resilience-building processes.

The purpose of this paper is to design a specific supply chain resilience framework to enhance supply chain resilience in the medical equipment industry. This section of the literature review therefore also studies the extensive literature on frameworks used to enhance supply chain resilience. These frameworks for enhancing supply chain resilience are mostly designed with the aim of maximizing the resilience capacity of the supply chain while minimizing the negative factors, thus facilitating rapid firm recovery (Pettit, Fiksel et al. 2010, Soni and Jain 2011, Aigbogun, Ghazali et al. 2014, Soni, Jain et al. 2015, Lakhal 2017). Soni and Jain (2011) described a new framework for supply chain resilience by incorporating flexibility, adaptability, collaboration, visibility, and sustainability as the major pillars for resilient supply chains. This framework provides a new means to evaluate `supply chain fitness' and also provides critical insights for decision-making by minimizing the negative impact of unavoidable risk events. And later, Soni, Jain et al. (2015) further studied the supply chain resilience framework, which also includes both adaptive capacity and vulnerability. Adaptive capacity refers to the ability to improve supply chain resilience, including flexibility, information, collaboration, visibility, and sustainability. Vulnerability, on the other hand, is analysed in terms of supply chain structure, supply side and demand side.

Aigbogun, Ghazali et al. (2014) developed a framework for enhancing pharmaceutical supply chain resilience which revealed 4 dimensions of supply chain vulnerabilities (Turbulence, external pressures, sensitivity and connectivity) and 6 dimensions of supply chain capabilities (flexibility, visibility, adaptability, collaboration, reserve capacity and supplier dispersity. Lakhal (2017) developed a supply chain resilience framework that will be used to reinforce the supply chain resilience and to minimise the negative impact of unexpected events thereby favouring a quick return to business in a turbulent environment when it is faced with unexpected events. This framework considered the four supply chain drivers – inventory, transportation, facilities, and information. Pettit, Fiksel et al. (2010) developed a conceptual framework for assessing and improving supply chain resilience, based on lessons learned from supply chain disruptions. This framework is derived from a translation of the concept of resilience and can be used as a useful management tool to improve performance.

Ehrenhuber, Treiblmaier et al. (2015) proposed a framework which is based on a comprehensive literature review and systematically integrates research from hitherto separated strands of SC research. This

framework connects various capabilities (changeability, innovativeness, flexibility, collaboration, visibility, and sensing) of SC resilience to companies' general objectives (survivability, sustainability, and robustness) and depicts organisational structure and processes as enabling factors.

Table 4 Overview of the literature of supply chain resilience

Authors	Title	Methodology	Type of SC	Main goal
Purvis, Spall et al. (2016)	Developing a resilient supply chain strategy during 'boom' and 'bust'	Case study-qualitative study	Food and drink sector	The main purpose of this paper was to explore one company's approach to translating relevant management theories into a supply chain resilience strategy, which it named robust, agile, lean and flexible (RALF).
Gunasekaran, Subramanian et al. (2015)	Supply chain resilience: role of complexities and strategies	Special issue papers	global sourcing	The main objectives include (i) explain the various aspects of GS rather than reporting the trends and implications described in the literature, (ii) view GS in terms of complexity theory and (iii) investigate the resilience of supply chain due to GS complexity and suggest strategies to overcome complexities.
Soni and Jain (2011)	Minimizing the vulnerabilities of supply chain: A new framework for enhancing the resilience	Qualitative analysis	-	The main goal is to provide a framework for enhancing the resilience to minimize the vulnerabilities of supply chain.
Soni, Jain et al. (2015)	Coping with uncertainties via resilient supply chain framework	The NKC model	-	The main purpose to propose a conceptual model for endowing deeper knowledge of how uncertainty from suppliers, customers and existing supply chain structure amplifies vulnerability and consequently increases supply chain risk exposure.
Hecht, Biehl et al. (2019)	Urban Food Supply Chain Resilience for Crises Threatening Food Security: A Qualitative Study	Semi-structured in-depth interviews	Food Supply Chain	The goal is to identify factors that may be associated with organization-level food system resilience, how these factors may play out in disaster response, and how they may relate to organizations' confidence in their ability to withstand disruptive events.
Nikookar, Takala et al. (2014)	A qualitative approach for assessing resiliency in supply chains	A qualitative approach based on multi criteria decision making process	automotive industry	The goal of this study is to develop a comprehensive and competitive management system to enhance resilience capability of supply chains.
Ehrenhuber, Treiblmaier et al. (2015)	Toward a framework for supply chain resilience	literature review		The purpose of this paper is to develop a framework which combines capabilities, enablers and objectives of resilience.

Lakhal (2017)	Towards a framework for a resilient supply chain in a turbulent environment: a review of its drivers	-	-	The goal is to build a framework to minimize the negative impact of unexpected events give a quick return to business in a turbulent environment.
Siva Kumar and Anbanandam (2020)	Theory Building on Supply Chain Resilience: A SAP–LAP Analysis	Case study	Automobile supply chain	The aim of literature is to find several concerns associated with SC resilience in the investigate company. A system thinking approach is needed to analyze the entire scenario of the resilience of the SC and the flexibility necessary to implement the best suitable resilience implanting processes.
Adobor (2019)	Supply chain resilience: a multi-level framework	Multilevel approach	-	The goal of this paper is to propose a multi-level framework to bridge a gap that very few studies have directly explored resilience at different levels of analysis.
Stone and Rahimifard (2018)	Resilience in agri-food supply chains: a critical analysis of the literature and synthesis of a novel framework	Systematic literature review	agri-food supply chains	The research lies in drawing on the broad understanding of resilience across research fields to develop a rigorous, food-specific resilience framework with a primary focus on end-consumer food safety.
Aigbogun, Ghazali et al. (2014)	A Framework to Enhance Supply Chain Resilience: The Case of Malaysian Pharmaceutical Industry	Semi-structured interviews	Malaysian Pharmaceutical Industry	The purpose of this paper is to design a resilient framework for the Malaysian Pharmaceutical manufacturing supply chain. This paper investigates the vulnerabilities and the capabilities and improve the supply chain resilience.
Pettit, Fiksel et al. (2010)	Ensuring supply chain resilience: development of a conceptual framework	Focus group research methodology	-	This study builds on lessons learned from supply chain disruptions to create a conceptual framework for evaluating and improving supply chain resilience.

2.3. Basic resilience framework structure

This paper is based on the design and improvement of the framework used to enhance supply chain resilience from the previous section, in particular the ideas of Soni, Jain et al. (2015), Aigbogun, Ghazali et al. (2014), and Ehrenhuber, Treiblmaier et al. (2015). Figure 2 shows the preliminary conceptual framework designed based on the above literature.

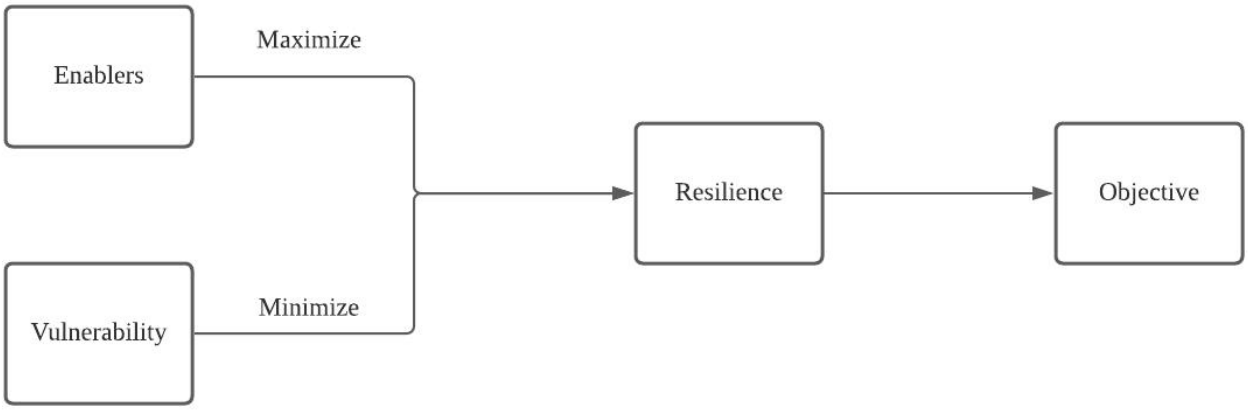

Figure 2 Preliminary conceptual supply chain resilience framework

Based on the frameworks designed by Soni, Jain et al. (2015) and Aigbogun, Ghazali et al. (2014), the supply chain resilience framework of this study will also be analysed from two aspects. One aspect is the vulnerability that is tried to reduce in the supply chain. The other aspect is the positive factors used to enhance the resilience of the supply chain. By analysing these two resilience frameworks, it is argued that such a design can be applied to the after-sales service supply chain of medical equipment. First, Soni, Jain et al. (2015) developed a supply chain resilience framework including both adaptive capacity and vulnerability aspects, and the framework does not limit the industries to which it can be applied. This suggests that the application of this framework is universal. Secondly, the supply chain framework developed by Aigbogun, Ghazali et al. (2014) also analysed both vulnerability and capability aspects. Furthermore, this framework is designed based on the pharmaceutical supply chain industry. The pharmaceutical industry is considered to be an industry that is constantly generating new products with the purpose of saving lives and improving the quality of life (Scherer 2000). This is very similar to the purpose of the industry of medical devices, which also aims to serve the patient (Durrant 2001). Therefore, we believe that the structural model of this framework can be used equally well for a supply chain resilience framework based on the context of the medical equipment industry. Finally, some literature similarly states that resilience can be analysed in terms of both vulnerabilities and capabilities (Pettit, Fiksel et al. 2008, Amir, La'ya et al. 2013). This also suggests the feasibility of designing the resilience framework in terms of both vulnerability and capacity.

As shown in Figure 2, the supply chain resilience framework for this research will include the element of vulnerability. These vulnerabilities can negatively impact the supply chain, and if the vulnerabilities that arise are addressed in a timely way, the performance and efficiency of the supply chain can be significantly improved. Identifying vulnerabilities that can impact the medical equipment industry before an incident occurs and assessing vulnerabilities to better plan and prioritize is effective in a resilient medical equipment supply chain. The SCR framework designed in this paper will provide important insights for decision making by minimizing supply chain resilience vulnerabilities. In contrast to the supply chain described above, another aspect included in the designed resilient framework is the enabler. The enablers are invisible, dynamic supply chain capabilities that can withstand supply chain disruptions or generate competitive advantage during normal, routine operating hours (Ehrenhuber, Treiblmaier et al. 2015). Jafarnejad, Momeni et al. (2019) also argues that the recognition of resilience enablers will play an important role in the competitiveness of the medical equipment supply chain. Although this is different from the supply chain capabilities proposed by the framework in most of the literature, enablers are also the factors which need to be maximized in supply chain management.

Ehrenhuber, Treiblmaier et al. (2015) developed a resilience framework that combines capabilities, enablers and objectives. Therefore, based on the elements included in this framework, the supply chain resilience framework to be designed in this paper will also link the enablers, vulnerabilities and the overall objectives of the after-sales service supply chain.

3 Designing the resilience framework

This chapter focuses on identifying the enablers, vulnerabilities and objectives in the framework. The main objective of this paper is to enable professionals to use this framework to enhance the resilience of the medical equipment after-sales service supply chain. Furthermore, it was found that the elements included in the vulnerability of the resilience framework designed by Aigbogun, Ghazali et al. (2014) are quite different from those in the framework designed by Soni, Jain et al. (2015), but the supply chain capabilities have the same components. This illustrates that the elements included in vulnerability and supply chain capability in the framework should be appropriately adapted to the characteristics of the applied industry. The enablers and vulnerabilities included in the framework need to fit the characteristics of the medical equipment after-sales service supply chain. Therefore, Chapter 3 firstly describes the characteristics of the medical equipment after-sales service supply chain and then identifies the enablers, vulnerabilities, and objectives that apply to enhancing supply chain resilience in this industry.

3.1. Introducing medical equipment after-sales service supply chain

The medical equipment after-sales service supply chain is not the same as other medical equipment supply chains discussed in the literature and has its unique characteristics. Therefore, a detailed understanding of the medical equipment after-sales service chain can help select the enablers, vulnerabilities, and objective components that are applicable to the medical equipment after-sales supply chain.

First, unlike other supply chains in the medical equipment industry, it is difficult for the medical equipment after-sales service supply chain to forecast future demand for spare parts, so sourcing personnel generally make plans to order spare parts based on historical data. Additionally, a very important performance indicator in the medical equipment after-sales service supply chain is customer satisfaction. Customer satisfaction in the after-sales service chain comes from the customer experience, which is influenced by the speed of the repair and the waiting time for the spare parts needed for the repair. If the customer can receive the spare parts in the shortest possible time, then customer satisfaction will be higher. So, transportation is a very important part of the after-sales service supply chain for medical equipment, and orders need to arrive on time. By studying the medical equipment after-sales service supply chain, it was learned that in order to make medical equipment spare parts available to customers as quickly as possible, companies usually choose air transportation when their budget allows.

Medical equipment belongs to the precision machine, for the transport environment requirements are very strict, different products have different requirements for the transport conditions. For example, some products are required to be temperature controlled, so special means are needed to ensure the temperature in transportation. The required spare parts are equally strict for transportation conditions. In addition, unlike other general products, for medical equipment-related products, once the external packaging is damaged during inspection, regardless of the severity of the damage, it needs to be discarded. Medical equipment has high environmental requirements for transportation, and some products need to be temperature controlled. Some products require temperature control, and once a product is damaged, it needs to be discarded.

Finally, some medical equipment companies are involved in a global supply chain, which makes the structure of the medical equipment after-sales service supply chain more complex and exposed to more risks. Therefore, when designing the supply chain resilience framework, it is assumed that the medical equipment after-sales service supply chain is a global one.

3.2. The conceptual resilience framework

The complete conceptual framework of supply chain resilience developed in this paper (Figure 3) consists of vulnerability, enablers, and objectives. Based on the characteristics of the medical equipment after-sales service supply chain. The resilience framework totally identifies 11 enablers and 5 vulnerabilities which are consist of both internal and external components. The objectives element includes satisfaction and sustainability. The next section describes the selected enablers, vulnerabilities, and objectives in detail.

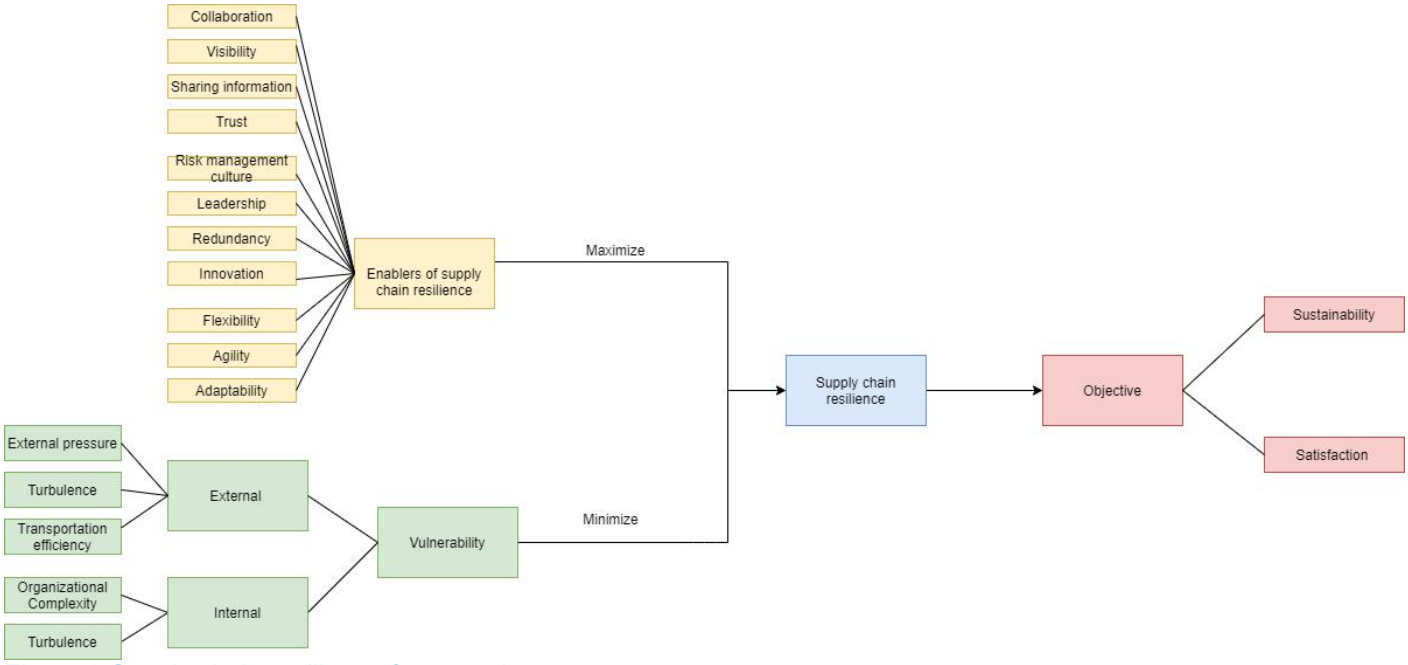

Figure 3 Supply chain resilience framework

3.3. Identifying enablers

Resilience is considered to be based on enablers (Lima, Da Silva et al. 2017) and identifying enablers is a key part of improving supply chain resilience. Based on the perspective of enhancing the medical equipment after-sales service supply chain, this paper summarizes 11 enablers that can be used to enhance supply chain resilience through extensive literature research.

1. Collaboration

   Collaboration refers to the ability to work jointly and effectively within an organization or with other supply chain entities to achieve mutual benefit (Lima, Da Silva et al. 2017). The ability of the medical equipment after-sales service supply chain is reflected in the coordination of various resources in sourcing, warehousing, and transportation, including human and physical resources, as well as non-physical resources such as information technology and strategic behaviour. Good capabilities can break through the barriers in supply chain collaboration. In the context of supply chain resilience, it is important to emphasize that internal collaboration is as important as external collaboration. For example, when there is a shortage of parts from suppliers, procurement needs to communicate with internal technical staff and front-end customers to prioritize orders to best meet customer needs. Sourcing also needs to communicate internally with R&D staff to find alternative parts, and externally with suppliers to seek backup. If there is no good collaboration, there will be supply chain disruption due to supply chain shortage, so good supply chain collaboration is considered to be the enabler of supply chain resilience.

   Barriers in a company's organizational structure or personnel communication are behavioural barriers that can also affect supply chain collaboration. For example, collaboration within the supply chain is reflected in the successful promotion of business. In large medical equipment companies, the division of responsibilities and processes is very detailed. When an after-sales service determines that a product

needs to be replaced with a spare part, the business has a process that requires the return of the product for repair, and after it is repaired and sent back, the process is followed to send the spare part. Therefore, a set of processes usually requires the participation of many departments, in which as long as there is a link of communication problems, the entire supply chain will immediately react. Collaborative enabler can influence all aspects of the supply chain. It is also important for the supply chain to return to a normal level of operation. Collaboration increases the ability to work effectively with other entities for mutual benefit.

2. Visibility

The visibility has been defined as “the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times of these events” (Jüttner and Maklan 2011). In supply chain resilience, visibility is the ability to be able to see transparently through all supply chain steps, to access accurate information that is important or useful in recovering from supply chain disruptions in a timely manner to reduce information asymmetry, and to be able to quickly identify demand and disruptions (Barratt and Oke 2007). Visibility implies knowledge of the state of operational assets and the environment and the ability to implement change in an effective manner. As such, it is a prerequisite for rapid response and recovery from disruptions (Kumar and Anbanandam 2020). In addition, visibility is associated with effective disruption response and recovery because supply chain visibility from the supplier to the after-sales customer enables the supply chain to achieve higher levels of response to market and mitigate the risk of parts disruption (Wei and Wang 2010).

3. Sharing information

Sharing information is an important aspect of coordination between parties in a supply chain. Information sharing can improve the efficiency of the supply chain by reducing inventory and smoothing production (Baihaqi and Beaumont 2006). With the rapid development of modern science and technology, companies are currently updating their information technology by using information technologies such as the Internet and e-commerce. These technologies are used to achieve efficient information sharing among supply chain members, which can see the order information among their upstream firms, as well as the order demand from downstream firms, and also receive the information demand from end users. Companies can integrate a range of information to make a more rational decision.

The efficiency of the supply chain is also very important because competition is no longer between companies today, but between supply chains (Lima, Da Silva et al. 2017). For the medical equipment after-sales service supply chain, it is especially important to share information. Keeping the latest, comprehensive information can help the supply chain quickly return to balance in the face of urgent situations. The medical equipment industry is closely related to the healthcare industry, and rapid supply chain recovery not only impacts the quality of after-sales service, but also saves patients' lives. In addition, information asymmetry can lead to the bullwhip effect. Sharing information will enhance the flow of information within the supply chain members, thus making the uncertainty of the centralized system greatly reduced and even eliminating the negative impact of the bullwhip effect.

4. Trust

For the after-sales service supply chain in the medical equipment industry, trust is very important to recover the status of the supply chain. As mentioned by Sahay (2003), the role that trust plays in a partnership comes to the fore when the partnership is in trouble. Trust works both ways in ensuring the integrity of any supply chain. Suppliers need their customers to trust that they will deliver the goods on time and at the agreed price. Likewise, buyers need to respect their suppliers and do their best to complete payment according to the agreed terms. Trust is instilled through a partner's ability to fulfil its commitments (Sahay 2003). Trusting relationships between supply chain members are an important component of building successful long-term coalitions. For example, medical equipment companies will have strategic partnerships with a number of suppliers, and an essential factor in becoming a strategic

partner is trust. The company trusts that the supplier will not raise prices or raise them to unreasonable levels in a crisis. In terms of trust in capability, medical equipment companies trust that spare parts suppliers are capable of delivering quality orders on time. This also means that trust is not something that happens overnight, but is built over time through repeated interactions and acts of goodwill.

In addition, Handfield and Nichols Jr (1999) stated that capability-based trust can be decomposed into three key domains. For trust in this framework, two of these domains are considered to be important for supply chain resilience. One is about specific capabilities, i.e., trust in the specific functional areas of other partners. For example, a medical equipment company that buys spare parts from a supplier trusts that the supplier will be able to answer any questions he may have related to the specific mechanical properties of the spare parts. Another area is interpersonal skills, i.e., a person's ability to work with others. For example, it is particularly important to effectively listen to another person and negotiate effectively when a breach occurs. These skills can help bring a supply chain back into balance during special times.

5. Risk management culture

Risk management culture refers to a culture that infuses resilience and risk awareness into everyone's focus. For example, some medical equipment companies pay great attention to risk management and have established a dedicated risk management platform. For example, hurricanes in the U.S. often affect supply chain operations, so the risk management department detects such events or takes measures in advance during high hurricane periods. Thus, after a disruption, the factor that clearly separates those companies that recover quickly and even profitably from those that falter is the risk management culture.

6. Leadership

The literature review by Mokhtar Mokhtar, Genovese et al. (2019) refers to SC leadership as a set of behaviours that are used to influence and coordinate the actions and behaviours of SC partners. For supply chain resilience leadership, the behaviours specifically refer to the commitment and support for implementing and maintaining supply chain resilience. This commitment and support is from the top management of the supply chain. Supply chain leadership differs from leadership by power or governance structures in that it aims to improve the collaborative behaviour of the entire SC rather than any individual participant (Mokhtar, Genovese et al. 2019). Therefore, leadership in this supply chain resilience framework aims to enhance the resilience of the entire supply chain.

7. Redundancy

Redundancy refers to the availability of assets to achieve sustained levels of production (Lima, Da Silva et al. 2017). More specifically, redundancy in a supply chain is the maintenance of more inventory or production capacity in the supply chain than is normally required. Generally, when there is an emergency disruption in the supply chain, the chain of commodity flow, cash flow, logistics and information flow is interrupted. The supply chain of medical equipment after-sales is mainly targeting customers, so the service performance and delivery capacity cannot be reduced, which will directly affect the company's customer business development. Therefore, the supply chain of medical spare parts requires timely delivery. Redundancy allows excess stock in inventory to be used to temporarily meet supply requirements in the event of a supply disruption. The ultimate goal is to keep the supply chain up and running. In traditional production, companies have safety reserves as a cushion in case of disruptions so that they have time to take measures, plan and resume production and operations.

8. Innovation

Innovation means going beyond organizational boundaries in an effort to continuously transform knowledge and ideas into new supply chain processes and systems for the benefit of supply chain development. In fact, innovation can solve problems in the supply chain by using available materials and knowledge to create ideas and insights that are different from those of ordinary people. Innovation

enhances supply chain resilience by increasing the resilience of the supply chain. Imagine a medical equipment company with a high level of innovation that is organized and managed differently, so it is difficult to bring down the supply chain with normal risks. Even if there is a disruption in the supply chain, the innovation team will think differently to solve the problem and get the supply chain back to work quickly.

9. Flexibility

   By the definition of flexibility "the ability to bend easily without breaking", we can see that flexibility is defined as an inherent part of resilience (Fiksel 2006). This inherent characteristic of flexibility may enable a supply chain to adapt to changes in a predetermined environment (Santos Bernardes and Hanna 2009). Flexibility can therefore be described as the ability of a supply chain to deal with the uncertainty caused by the environment in a firm's production operations and to respond and adapt to uncertain situations with minimal time, effort, cost and performance degradation (Giunipero, Denslow et al. 2005). Flexibility can be applied to an organization and the entire supply chain, so flexibility is thought to improve supply chain resilience by enhancing transient versatility in the midst of turbulence and helping to quickly respond and restore the state of the supply chain (Chopra and Sodhi 2004, Sheffi and Rice Jr 2005, Christopher and Holweg 2011).

10. Agility

    Agility is viewed as an approach for a rapid reconfiguration of a system when faced with unpredictable changes (Santos Bernardes and Hanna 2009). Therefore, the agility of the supply chain emphasizes quick to respond. Agility refers to the ability of the supply chain to quickly respond to unpredictable changes in demand and supply, and the ability to quickly change the direction of action or adjust the action strategy during the reaction process. For the after-sales service in medical equipment industry, the supply chain is connected from service engineers, suppliers, distributors, forwarders and end customers into a whole body that involves the flow of goods, capital, logistics, and information flow. If the customers received the products is within the prescribed period of time and the results did not cause a lot of damage. Furthermore, according to the definition of supply chain resilience, it does return to the original operating level. That shows that agility has positive impact on supply chain resilience.

11. Adaptability

    According to Pettit, Fiksel et al. (2010), adaptability is the ability to modify operations in response to challenges or opportunities. Adaptability can be used to take advantage of recovery from supply chain disruptions by quickly rerouting demand and reducing lead times. Adaptability is the ability of supply chain members to adjust to the current situation and to effectively handle supply chain disruptions as they occur. For example, chips are an important component for medical equipment, and the chip market is currently in a short supply situation. In this case, the standard daily planning process cannot be adapted to the current situation. Under normal circumstances, purchasing can place an order to the supplier according to the lead time, and the supplier will ship the goods on time. If there is a need to rush the order, the supplier can expedite the order. However, due to the shortage of chips, the procurement of medical equipment after-sales service supply chain cannot use the daily standard process. Therefore, when placing orders again, the supply chain needs to be provided with a confirmed forecast demand. Adaptability is the ability to adjust the supply chain to changes in the supply chain due to the impact of external changes on the supply chain.

In summary, we have identified a total of 11 enablers for use in the supply chain resilience framework, as shown in Table 5.

Table 5 Enablers of the supply chain resilience framework

NO.	Enablers	Definition	Authors
1	Collaboration	The ability to joint efforts and work effectively within an organization or with other supply chain entities for mutual benefit. In resilience context stresses the importance of internal and external communication (Lima, Da Silva et al. 2017).	Christopher and Peck (2004), Scholten, Scott et al. (2014), Scholten and Schilder (2015), Tukamuhabwa, Stevenson et al. (2015).
2	Visibility	Visibility means an ability to get critical information to the people who need it in a timely manner. Both internal and external to the supply chain to monitor, control and change the strategy and operations of the supply chain from service procurement to delivery (Schoenthaler 2003).	Christopher and Peck (2004), Ehrenhuber, Treiblmaier et al. (2015), Tukamuhabwa, Stevenson et al. (2015)
3	Sharing information	The ability to share important, and possibly proprietary, information among supply chain members and inside organization Pettit, Fiksel et al. (2010).	Lee and Whang (2000), Christopher and Peck (2004), Faisal, Banwet et al. (2006), Dekker, Sakaguchi et al. (2013).
4	Trust	Trust is an attitude, and trusting relationships between supply chain members are considered a key factor in building successful long-term alliances (Lima, Da Silva et al. 2017).	Sahay (2003), Dekker, Sakaguchi et al. (2013)
5	Risk management culture	Make a culture of resilience and risk awareness the focus of everyone's work in the supply chain.	Sahay (2003), Christopher and Peck (2004)
6	Leadership	Leadership for supply chain resilience refers to a commitment and support from the top management of the supply chain to implement and maintain supply chain resilience.	Wilcock and Boys (2014), Kamalahmadi and Parast (2016)
7	Redundancy	Resources that can be invoked during a supply chain disruption to replace losses during a supply chain disruption. In other words, redundancy refers to the resources needed to prepare for excess normal during routine periods.	Sheffi and Rice Jr (2005), Soni, Jain et al. (2015), Tukamuhabwa, Stevenson et al. (2015)
8	Innovation	Moving beyond organizational boundaries and trying to continuously transform knowledge and ideas into new processes and systems for supply chain resilience enhancement.	Ehrenhuber, Treiblmaier et al. (2015), Wang, Jie et al. (2015)
9	Flexibility	The ability of the supply chain to handle the uncertainty caused by the environment in the production and operation activities of the company, reacting and adapting to changing requirements with minimal time, effort, cost and performance degradation (Lima, Da Silva et al. 2017).	Soni, Jain et al. (2015) Tukamuhabwa, Stevenson et al. (2015), Wang, Jie et al. (2015)
10	Agility	The ability to react and adapt quickly to changes and potential or actual unpredictable events.	Christopher and Towill (2001), Christopher and Peck (2004), Schoettle and Sivak (2014), Tukamuhabwa, Stevenson et al. (2015)

11	Adaptability	The ability to modify operations in response to challenges or opportunities.	Briano, Caballini et al. (2009)

3.4. Identifying vulnerabilities

Asbjornslett (1999) defined the concept of vulnerability as it applies to production systems that " A robust and resilient system is capable of supporting or absorbing catastrophic failures and sustaining them without disruption." According to this paper, the vulnerabilities in this framework will be identified separately from the external and internal aspects of the supply chain. This resilience framework identified a total of 5 vulnerabilities from both internal and external to the supply chain, which can be viewed in the Table 6 below.

Table 6 Vulnerabilities of the supply chain resilience framework

	Specific (type of) vulnerability	**Definition**	**Why relevant?**
Internal	Supplier disruptions	Any external event that hampers the provision of goods at the start of the supply chain.	If supply fail, the supply chain will keep away from its original situation and reduce the performance. Therefore, the unexpected supplier disruption will influence the efficiency of the supply chain, and reduce the supply chain resilience.
	Organizational Complexity	The complexity of an organization refers to the number of resources that are involved in a division, project, or team.	Complex organizational structures can affect the speed of decision making. Thus, if an unexpected risk event occurs, the supply chain organization will not be able to react quickly to potential disruptions to return to the original situation, or a more desirable balance.
External	External pressures	External pressures mean the influences, not specifically targeting the firm, that create business constraints or barriers (Pettit, Croxton et al. 2013).	External pressures include new policies or regulations, price pressures, innovation competition, etc. These external pressures can affect the current state of balance in the supply chain,
	Transportation efficiency	The transportation efficiency can be affected by the state of the infrastructure which is an external factor. Transportation efficiency for the medical equipment supply chain refer to reduce the possibility of the order delay, resulting in less time in transportation.	If the transportation is not efficient, the delivery of the order will be delayed. Moreover, the satisfaction of customers may go down. Because customers always expect can receive the medical equipment spare parts as soon as possible. This delivery delay and the low satisfaction will influence the supply chain resilience.
	Turbulence	Turbulence which can influence the supply chain resilience refer to the environment characterized by frequent changes in external factors beyond your control (Pettit, Croxton et al. 2013). Therefore, the turbulence is something with volatility and uncertainty that supply chains have always had to deal with.	If the turbulence happened, the supply chain will disrupt. Thus, turbulence is a potential risk that can change the original situation of the supply chain. Turbulence is regard as a vulnerability that can reduce the supply chain resilience.

There are two vulnerabilities related to internal, one is supplier disruption and the other is organizational complexity. Supplier disruption is defined as that any external event in the supply chain that hinders the

availability of goods. This vulnerability refers to the susceptibility of the supplier to external forces or disruptions (Pettit, Croxton et al. 2013). Supplier disruption is identified as one of the vulnerabilities because if supply fails, the supply chain will keep away from its original situation and reduce the performance. Therefore, the unexpected supplier disruption will influence the efficiency of the supply chain, and reduce the supply chain resilience. For example, an unpredictable fire at a supplier's warehouse affects the supplier's ability to provide products. For the medical equipment after-sales service supply chain, such a situation would require timely back-up from other suppliers, and supply chain resilience would be affected by supplier disruptions if other suppliers are not available in a timely manner.

The complexity of an organization can be judged by the number of resources involved in a department, project, or team. An organization is considered complex if the size of its structure or the number of decision-makers involved is large. Complex organizational structures can affect the speed of decision-making. Thus, if an unexpected risk event occurs, the supply chain organization will not be able to react quickly to potential disruptions to return to the original situation or a more desirable balance. Therefore, organizational complexity is thought can affect supply chain resilience. In addition, a complex organizational structure may also affect the transmission of information, thus causing those who need to receive information to not receive it in a timely manner. This can also prevent the supply chain from acting on unexpected situations in a timely manner, which can affect supply chain recovery.

The remaining three vulnerabilities are all externally related. The first is external pressures, which Pettit, Croxton et al. (2013) considers to influence that are not specific to the business, but that create limitations or barriers to the business. External pressures include new policies or regulations, price pressures, innovation competition, etc. These external pressures can affect the current state of balance in the supply chain, so identifying external pressures and taking timely action can prevent supply chain resilience from being affected. For example, political/regulatory changes. Many medical equipment companies, in particular, are involved in global supply chain operations. When import or export policies for medical devices or related parts change, the supply chain regulations within the company need to be adjusted accordingly. If the tariff on a product is too high and affects the company's profit, then procurement needs to take timely action or the flow of funds may be affected. When these political/regulatory changes have a negative impact on medical device companies, the resilience of the supply chain may be reduced as a result.

The condition of the infrastructure in the supply chain is an external factor. The efficiency of transportation is usually influenced by the state of infrastructure. Therefore, the efficiency of transportation is considered as another external factor. The efficiency of transportation in the medical device supply chain refers to reducing the possibility of order delays and thus reducing transportation time. If transportation is not efficient, the delivery of orders will be delayed. Customer satisfaction will also be decreased as a result. Customer satisfaction and delivery efficiency is a very important indicator for the after-sales supply chain of medical equipment. This is because customers always want to receive spare parts for medical equipment as soon as possible. Such delivery delays and low satisfaction levels will affect the resilience of the supply chain. For example, during the covid-19 pandemic, the transportation of goods for medical equipment companies was somewhat affected, and flight routes between countries were restricted. As a result, transportation routes had to be changed and order delivery times were impacted as a result. This situation affected the supply chain is state, as customers took longer to receive their goods, so customer satisfaction received an impact. Identifying the factors that affect the efficiency of transportation and improving the efficiency of transportation can help restore the supply chain to a better state.

The last identified external vulnerability is turbulence. Pettit, Croxton et al. (2013) considered turbulence that can affect supply chain resilience as an environment characterized by frequent changes in external factors beyond your control. Therefore, turbulence is a factor with volatility and uncertainty that supply chains always need to deal with. The probability of turbulence occurring is relatively low, but when it does, the probability of the supply chain facing disruption is very high. Therefore, turbulence is a potential risk that can change the original condition of the supply chain. Turbulence includes natural disasters such as earthquakes, currency fluctuations, pandemics, etc. For example, the still ongoing covid-19 affected supply chains worldwide. The closure of many cities and countries caused supply chain disruptions in a variety of industries. Therefore, turbulence is considered a vulnerability that can reduce the resilience of supply chains.

3.5. Identifying objectives

This resilience framework identified two main targets of resilience, which represent the intended outcomes of medical equipment with the enhanced resilience. One objective is sustainability and the other is high customer satisfaction.

Sustainable supply chain management is supply chain planning and decision making that includes economic, social and environmental sustainability dimensions (Kusi-Sarpong, Gupta et al. 2019). Currently, sustainability is receiving increasing attention in the supply chain (Sajjad, Eweje et al. 2020), moreover, many medical equipment companies have adopted sustainability as a company development strategy because sustainable supply chains benefit the environment, society, and the economy. Therefore, improving supply chain sustainability is also a challenge for the after-sales service supply chain of medical equipment. Ahern (2013) mentioned that without resilience, the system can only have fragile sustainability. Additionally, Anderies, Folke et al. (2013) also said that sustainability provides the objectives of the system and the concept of resilience is used to achieve these objectives. For the supply chain, disruptions in the supply chain will affect the sustainability of the supply chain in environmental, social and economic terms. For example, Covid-19 caused many countries to lockdown and close factories. This caused disruptions in the supply of spare parts for medical equipment, making it take longer to repair medical equipment and thus having an impact on saving patients. This affected not only the economic aspect, but also the social aspect. Therefore, supply chain sustainability is ensured by strengthening supply chain resilience so that the supply chain can still function as normally as possible in case of problems. Finally, in the resilience framework designed by Ehrenhuber, Treiblmaier et al. (2015), the objective is also involved. Therefore, in this framework, sustainability is considered to be an objective that can be accomplished by enhancing the resilience of the supply chain.

Based on the characteristics of the medical equipment after-sales service supply chain described in section 3.1, we learned that customer satisfaction is a very significant performance indicator for the supply chain. And the ability to receive supply chain spare parts on time for repairs can have an impact on customer satisfaction. The purpose of this framework is to help managers diagnose the supply chain and thereby improve supply chain resilience. Thus, by maximizing the enablers in the framework and minimizing vulnerabilities, the supply chain becomes more resilient and the impact of disruptions is reduced. This allows the medical equipment after-sales service chain to maintain a high level of service by allowing orders to arrive on time while facing a complex global environment. Thus, by applying the resilience framework designed in this paper to diagnose and enhance supply chain resilience, the supply chain objective of improving customer satisfaction will be achieved.

4 Operationalizing the supply chain resilience framework

Operationalization means transforming abstract concepts into measurable observations. By operationalizing the factors in the supply chain resilience framework, supply chain managers can better measure the supply chain's enablers and vulnerabilities. Operationalization works by identifying the specific indicators that will be used to represent the given enablers and vulnerabilities.

4.1. Operationalizing the enablers

By operationalizing this, managers can systematically collect data on various enablers that cannot be directly observed. Table 7 shows the specific indicators used to measure enablers.

Table 7 The indicators for the enablers

Enablers	Indicators
Collaboration	Frequency of collaborative forecasting Efficiency of communication Supplier delivery efficiency
Visibility	Level of information technology Degree of information exchange Forecast error Ease of acquiring the information
Sharing information	Accuracy of forecast Inventory management efficiency Probability of uncertainty
Trust	Time that the relationship lasts between the buyer or the seller Confidential information sharing Existence of mutually beneficial cooperation terms
Risk management culture	Incentive and Punishment of risk management culture Level of knowledge of risk management Risk management culture training
Leadership	Number of resilience strategies or decisions Magnitude of supply chain resilience power Degree of leadership understanding of supply chain resilience
Redundancy	Quantity of stock. Warehouses and facilities spread
Innovation	Percentage of innovations adopted Innovation in services
Flexibility	The spare part-supplier rate Rate of deliver on time Customer evaluation
Agility	Time to respond Time to access relevant data Time to detect threats
Adaptability	Speed of re-routing the requirements Learning from experience

1. Collaboration

   Whether to use collaborative forecasting influences the activities' plan in the supply chain. Each organization in a supply chain has its plan for its activities, and within each organization many more often unrelated plans exist. If the organizations in a supply chain do not take into account other internal plans and activities that will undoubtedly impact the outcome of a particular plan, these plans will be doomed to failure (Ireland and Bruce 2000). Therefore, the frequency of using collaborative forecasting in the supply chain can be used to measure collaboration.

   Collaborative communication is the process of contact and information transfer between supply chain partners in terms of frequency, direction, mode, and impact strategy (Goffin, Lemke et al. 2006). The efficiency of collaborative communication with the internal and external aspects of the supply chain affects the internal and external process collaboration. More specifically, the quality of information can be used to measure the effectiveness of communication. The use of clear messages can reduce duplicate communication and avoid wasted time. Therefore, the efficiency of collaborative communication can usually be used to measure collaboration in the supply chain.

   Supplier delivery efficiency, which refers to the effectiveness of supplier shipments. First of all, if you want to be sure that the supplier can deliver on time, then purchasing needs to communicate with the supplier to determine a delivery time period that is acceptable to both the supplier and yourself. In addition, for special periods of delivery efficiency, such as the need to expedite and increase the volume. If you want such an unconventional order to be shipped on time, then collaboration between the purchaser and the supplier is also essential. The purchaser needs to ask the supplier if they can meet their needs and communicate the fastest possible delivery time.

2. Visibility

   The level of advanced information technology can influence the visibility of information. Information technology facilitates the transmission of information and increases the transparency of information in the supply chain. Advanced information technology can enhance the visibility of the supply chain by improving the information management in the supply chain. Visibility can therefore be measured by determining the level of information technology currently in supply.

   The degree and frequency of information exchange influence the symmetry of information in the supply chain. A high frequency of information exchange can avoid the information asymmetry in the supply chain in order to enhance resilience. Therefore, the degree of information exchange can also be used to measure the visibility of the supply chain.

   The error can be measured by calculating the percentage difference between forecast and reality. Calculating the percentage requires comparing previous demand, transportation, and other forecasts with what actually happened. When supply chain visibility is too low for planners, forecasters will not be able to take into account many important factors, leading to biased results.

   The ease of acquiring the information can be used to measure the supply chain visibility. When it is easier to obtain information, it indicates a high level of visibility in the supply chain. In addition, the ease of acquiring a particular piece of information is a fairly subjective measure. So, the indicator can be measured by giving a score from 1 to 10.

3. Sharing information

   Sharing information allows each member of the supply chain to make more accurate forecasts of what is going to happen in the future based on comprehensive and accurate information, which is beneficial for the supply chain to resist disruptions. Additional information in the supply chain can help organizations change existing plans or develop future operations. Therefore, the accuracy of forecasting will be used to measure information sharing in the supply chain.

Lee, So et al. (2000) and Zhao, Xie et al. (2002) claimed that if information sharing is used efficiently, the manufacturers are able to reduce the costs and inventory. Thus, to some extent, lower inventory and fewer costs mean the information sharing is effective. Therefore, the efficiency of inventory management can be used to measure information sharing.

In the supply chain, lacking information will cause uncertainties. If the members have the ability and willingness to share information with other members, uncertainties can be significantly reduced. Therefore, the probability of uncertainty can be considered as an indicator to measure sharing of information.

4. Trust

The length of time that the relationship lasts is an indicator of trusting behaviour between the buyer or the seller. The longer the relationship lasts, the greater the level of trust between the two parties (Sahay 2003).

The extent to which suppliers share private information with customers is thought to measure the level of trust between buyers and sellers (Sahay 2003). Thus, the extent of confidential information sharing can be used as a measure.

Handfield and Nichols Jr (1999) stated that one indicator that can be used to measure supply chain trust is the acknowledged assumption or acceptance of responsibility by one party to protect the rights and interests of the other. Therefore, it can be argued that both partners are considered to be trusting if there are mutually beneficial terms in the supply chain partner's contract.

5. Risk management culture

Supply chain organizations encourage supply chain members to consider risk management in their daily work by creating incentives and penalties related to risk management. Therefore, the availability of incentives and penalties for a risk management culture in the supply organization can be used to measure the risk management culture.

The level of knowledge of risk management by supply chain professionals influences supply chain risk. The organization or manager is very knowledgeable about the risk factors in the medical equipment supply chain, then the organization or manager always takes risk into account in the decision-making process and conducts a risk assessment before making a decision. Therefore, the risk management culture in the supply chain can be measured by the level of knowledge of risk management.

Companies that take supply chain risk seriously are likely to train their employees on risk management. Therefore, the supply chain organization's willingness to provide risk management training to supply chain members on a regular basis can be considered an indicator of the risk management culture within the organization.

6. Leadership

The more attention supply chain organizations give to supply chain resilience management, the more support upper management will give to decisions or actions related to enhancing supply chain resilience. Thus, the percentage of strategies or decisions on resilience to total strategies or decisions over a fixed period can be used to measure supply chain resilience leadership.

Sharif and Irani (2012) claimed that power is positively related to achievement. To increase the probability of success in enhancing the resilience of the supply chain, then the greater the power related to the resilience of the supply chain has to be. Therefore, the magnitude of supply chain resilience power can be used as an indicator.

The level of knowledge about resilience influences the ability of leaders to make resilience decisions. The more a supply chain department or manager knows about supply chain resilience, the more there is an indication of strong supply chain resilience leadership.

7. Redundancy

   To identify redundancies in the supply chain, it is often necessary to check the quantity of stock. An actual quantity of stock greater than the planned quantity can provide managers with more time to come up with an effective solution. Therefore, stock levels can be used to measure the presence of redundancies in the supply chain.

   The company that had warehouses and facilities spread throughout the world was able to bounce back relatively quickly. Thus, the distribution of warehouses and facilities can be used to measure the redundancy of the supply chain.

8. Innovation

   If a company has an innovation platform that encourages employees to actively participate in innovation, then employees can offer their ideas through the company's innovation platform. However, not all ideas turn into innovations that belong to the company, so the percentage of the number of innovations that have been adopted in a year to the total number of innovations proposed in a year can be used as an indicator to measure innovation. This percentage shows whether the medical equipment company has the ability to be able to apply the proposed innovations in practice. If the percentage is high, it means that the company is more capable of acting on innovation, and then the degree of innovation for the supply chain is higher.

   This supply chain resilience analysis is about the after-sales service in the medical equipment. Therefore, providing maintenance and repair service to customers is an important part of the after-sales supply chain. Innovation in service can provide new service modes or new terms of service that can improve customer satisfaction. Therefore, the presence of service innovations in the after-sales supply chain can be used as a measurement indicator.

9. Flexibility

   The spare parts-supplier ratio is used to check how many suppliers a part can be supplied by. A spare part is supplied by more than one supplier is considered to be flexible. This is because relying on single sourcing as a supply chain strategy exposes the company to the possibility of not having access to critical supplies in the event of a disaster disrupting supplier operations. If the spare parts-supplier ratio is 1: n (n>1), then when one supplier fails to deliver an order on time, the other suppliers will back up in time to avoid supply chain disruption.

   The rate of delivery on time is an indicator that can be used to reflect the flexibility of logistics. Flexibility in logistics management is one of the most important challenges. It needs the logistic quickly response as the industry requirement. For example, during the covid-19, some air routes have been closed. The medical equipment company should change the transportation plan timely to avoid the delivery delay.

   This indicator of customer evaluation can be used to reflect the flexibility of the service. The indicator can be measured by giving a score from 1 to 10. This paper research the after-sales services supply chain which provides maintenance and repair service. Thus, it is important for the staffs to provide a flexible service that meets customers' requirements.

10. Agility

    When the supply chain suffers an external attack, for example, if it can quickly adjust the plan to help the commodity flow, cash flow, logistics, and information flow can still keep up with. This will be a

process of rapid response. The length of time it takes to adjust the plan can usually be used to measure the agility of the supply chain, and we also call this indicator the time to respond.

Once the medical equipment company is influenced by unpredictable events, it must be able to speedily access relevant data in order to quickly decide how to act. Such as, the company may improve data accessibility within their supply chains by investing significant resources. So, the time to access the relevant data can be used as an indicator to measure agility.

In the framework, there are some vulnerabilities that have negative effects on supply chain resilience. Medical equipment companies need to have a high level of alertness. An agility supply chain can use less time to sense impending disruptions, be they natural or man-made disasters. Therefore, the time used to detect these threats can be used to measure the agility of the supply chain.

11. Adaptability

When the supply chain is disrupted, equipment needs to be rescheduled. A fast supply chain re-route of demand can indicate a good supply chain adaptability. Therefore, the speed of re-routing requirements is considered as an indicator to measure adaptability.

The improvement of adaptability is closely related to previous experiences. Supply chain organizations can continuously improve their problem-solving ability by summarizing their previous experiences and decisions. Thus, adaptability of the supply chain can be improved. Therefore, whether the supply chain organization is conscious of learning from experiences can be used as an indicator of adaptability.

4.2. Operationalizing the vulnerabilities

By operationalizing the vulnerabilities in the resilience framework, managers can more easily identify vulnerabilities in their supply chains and thus take timely action to avoid supply chain disruptions that could affect supply chain resilience. Table 8 shows the specific indicators used to measure vulnerabilities

Table 8 Indicators of vulnerabilities

Vulnerabilities	Indicators
Supplier disruptions	Frequency of occurrence per type of event. Level of the supplier reliability. Number of suppliers per type of goods.
Organizational Complexity	Number of the hierarchical layer of the organizational chart. Number of the decision makers involved in a project. Number of the processes and rules
External pressures	Product sales volume Monitoring the political events Price fluctuations
Transportation efficiency	Time of customs inspection Number of the delayed transportation orders
Turbulence	None

1. Supplier disruption

Calculating the frequency of each type of event that could cause disruptions to supply can be used to measure supply disruptions. This is because the probability of a possible supply chain disruption can be known through this indicator.

The level of supplier reliability can also be used to measure supply disruptions. This is because if the supplier is reliable to the company, the likelihood of supply disruptions due to problems with the supplier is reduced, and the ability to produce and respond to unexpected situations is considered to indicate the reliability of the supplier.

The number of suppliers per type of goods is also used as an indicator. Because more suppliers for one spare part mean more flexibility and less vulnerability.

2. Organizational complexity

   The complexity of an organization can be measured by counting the number of layers in the organization chart. However, for now, it is difficult to give a certain number as a threshold to measure the complexity of the supply chain organization structure, because this number needs to be adjusted according to the size of the company.

   The complexity of an organization can be identified by calculating the number of people involved in a project's decision-making process. If the organizational structure is complex and the rules and regulations are complicated, then many people need to be involved in a decision. However, it is also difficult to give a specific number of decision-makers to measure the complexity of a group structure, because this number needs to be adjusted according to the actual project situation.

   The number of the processes and rules can also be used to measure the organizational complexity. There are people, processes, rules, strategies, and basic units in an organization. If the processes and rules increase the workload and response time. These kinds of rules and processes can be said to be redundant.

3. External pressure

   Product sales volume can be used to measure the external pressure from competitors. By comparing the product sales volume with those of competitors, it is possible to know whether there is external pressure from competitors. If the growth rate of a competitor's product sales volume is greater than your own company's product sales volume, external pressure has emerged and measures need to be taken to minimize it.

   Monitoring relevant politics/regulations can be used as an indicator of external pressures. Medical equipment companies should keep an eye out for new politics/regulations related to the medical equipment industry or company's business, as this can affect the supply chain's strategy and work plans. For example, medical equipment companies with import/export operations need to pay attention to policies related to foreign companies with which they have partnerships. If the trade policies between the two countries are harsh, this will have an impact on the supply chain, so it is necessary to monitor the relevant politics/regulations and respond to them in a timely manner to minimize their impact on the supply chain. These politics/regulations can be found in newspapers or official documents, so it is possible to keep an organized focus on new politics/regulations that may have an impression on the supply chain.

   Price fluctuations can also be used as an indicator. External pressures are measured by observing price fluctuations in the market for the required products over the past few months or the past year. If the price of the required spare parts continues to rise in a short time, then the company needs to react to this continuous price increase. The company should investigate the reasons for the price increase and take timely measures to reduce the impact of the increase on the supply chain.

4. Transportation efficiency

   The time of customs inspection is regarded as an indicator to measure transportation efficiency. For global supply chains, importing and exporting are daily operations that will be involved in the supply chain. Customs clearance is an essential part of cross-border transportation, and the time to customs inspection is not completely certain, and in the case of special circumstances, the time to pass has to be extended. The time it takes to pass affects the efficiency of transportation, and longer customs inspection times can lead to delays in orders.

The number of delayed orders is considered to be an indicator of transportation efficiency. Different transportation routes can make the efficiency of transportation different, and the inefficiency of transportation can make the transportation time longer, and the delayed delivery of orders can occur. Therefore, it is considered to measure the efficiency of transportation by calculating the number of orders delivered late due to the impact of transportation efficiency.

5. Turbulence

The changes are usually beyond the control of the supply chain organization. It is hard to observe the turbulence in the supply chain. Therefore, there is no indicator that can be used to measure the turbulence.

4.3. The interaction between enablers

By analyzing the indicators used to measure the enablers, it is clear that there is an overlap between the indicators of the different enablers. For example, sharing information and visibility are both information-related enablers, so the indicators used to measure them are related to forecasting, so it is very important to briefly explore the relationship between the different enablers in the framework through the identified indicators. Figure 4 shows the supply chain resilience framework which shows the relationship between the different enablers.

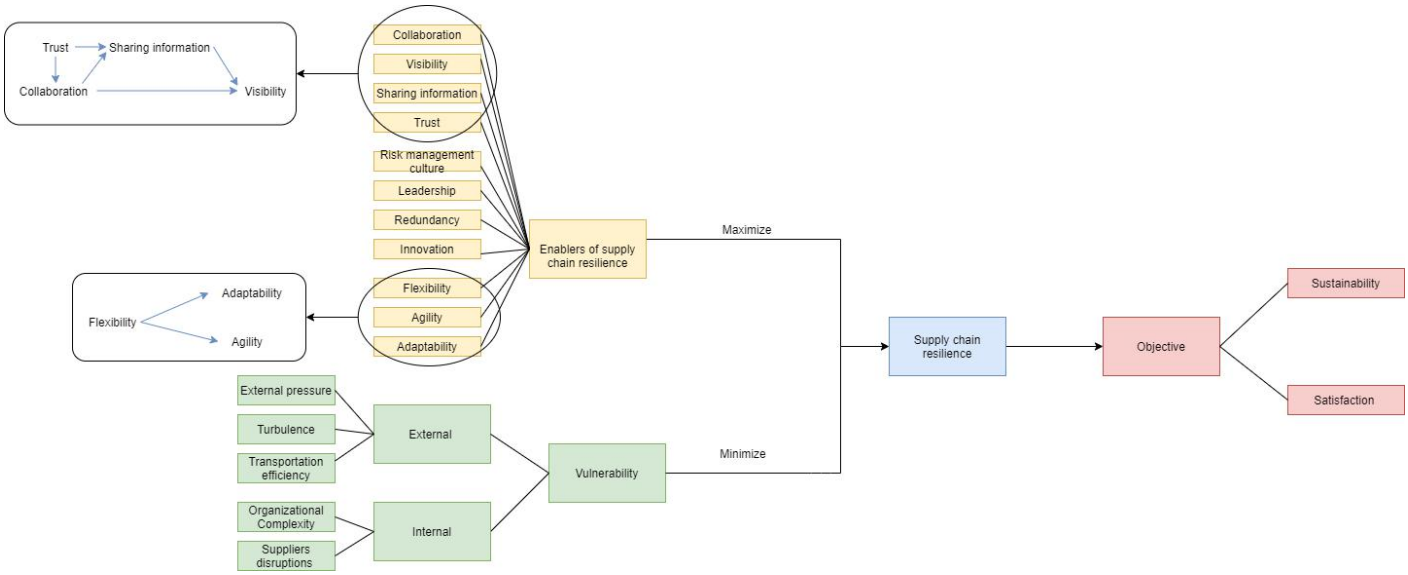

Figure 4 Relationship between different enablers

In the supply chain resilience framework, we find some similarities in the definitions of agility, adaptability and flexibility. They are all about the ability to adapt to new situations in the supply chain. Where agility emphasizes adapting quickly to changes to increase response time (Choi and Hong 2002). In terms of supply chain resilience, (2002) argues that agility is needed to be agile and to be able to react quickly to different situations. Furthermore, Lee (2004) explains flexibility by using agility and adaptability. Flexibility also is the ability to respond to any future changes, and this ability is also considered as adaptability. Therefore, in this framework of supply chain resilience, the relationship between agility, adaptability, and flexibility is shown in the figure below.

Scholten and Schilder (2015) stated that both sharing information and collaborative communication contribute to the visibility of the supply chain. Furthermore, collaborative communication and sharing of information are activities that involve supply chain collaboration across different organizations (Cao, Vonderembse et al. 2010, Scholten and Schilder 2015). Therefore, it makes logical sense to use the indicators of collaboration and sharing information to measure visibility. Meanwhile, because sharing information is one of the activities of supply chain collaboration, there is also a strong link between sharing information and collaboration. Talavera and Gloria (2014) argued that trust can make it easier for parties to come together for collaborative planning. Sridharan and Simatupang (2013) claimed that sharing

confidential information is a signal of integrity between partners. Therefore, sharing information can likewise be used as a measure of trust.

5 Testing procedure

In order to verify that the designed resilience framework is applicable to the medical equipment after-sales service supply chain and can enhance the supply chain resilience would require field testing in a series of case studies. However, this thesis project did not allow the time to do a real field test. Therefore, we settled for a “face validity test” with professionals via a questionnaire and semi-structured interviews. In this section, we provide more details on the procedure we followed.

5.1. Design the original interview questions

The interview process is divided into two major parts, and the full interview questions can be viewed in Appendix A. The first part explores the importance of the enablers and vulnerabilities presented in the supply chain resilience framework. The second part tests whether the indicators obtained through observation adequately measure the enablers and vulnerabilities in the framework. Therefore, the interview questions were developed based on the designed flexible supply chain framework. Because there are more enablers in the supply chain resilience framework, there is a correspondingly larger number of questions to be interviewed. This resulted in a long time to complete an interview. The target group of the interview is the employees in supply chain positions in medical equipment companies, who are busy with their work. Therefore, the long interview time will make the interview difficult. In order to improve the efficiency of the interview, the second part of the interview will not cover all the questions, but only the questions that the interviewee considers to be the most important elements in the first part.

5.2. Pre-test the original interview questions

In order to improve the interview questions and to make the interview run smoothly. A pre-test section will be designed to test the designed interview questions before the formal interview. In the pre-test interview section, people with supply chain knowledge backgrounds will be interviewed. In this section, a total of five people were interviewed, and Table 9 illustrates the background of the interviewees. Prior to testing, interviewees were informed that their interviews were voluntary and confidential. Interviewers were also informed of the purpose of the interview. The feedback received at the end of each interview was used to immediately modify the interview questions. The revised interview questions would be used directly in new interviews so that the interview questions would be continually revised and refined.

Table 9 Background of the interviewees

No.	Position	Background
1	Student	The major is transport & logistics
2	Staff-procurement	Medical equipment industry
3	Staff-procurement	IT industry-Virtual Products
4	Staff	Consulting-manufacturing industry
5	Staff	Worked in various departmental rotations-manufacturing industry

The designed pretest section involves the following main purposes:

1. To confirm whether the interview questions can be understood by interviewing people with supply chain management background and whether there are any overly specialized terms that make the interviewees not able to understand the questions accurately.

2. To explore whether the interview questions are well designed by communicating with the interviewees. If not, which questions need to be improved?

3. To find out how the interviewees feel about participating in the interview, and to find out whether the interview process is designed efficiently.

4. To estimate how long a complete interview will take through pre-testing.

By pretesting the interview questions, we received feedback on the designed interview questions from different test participants. All participants pointed out that the words chosen for the designed questions were too specialized. The test revealed that different participants had different levels of understanding of specialized vocabulary, as the words that each person found difficult to understand were also different. This may be related to the different backgrounds of the participants, with some participants knowing more about the supply chain and being more specialized, while others were limited to understanding what would be involved in their daily work. The interviewed participants were generally employees from different medical equipment companies. They have different job positions and different levels of understanding of supply chain resilience, and therefore encounter such problems in the actual interviews. Participants may not always understand the specialized vocabulary of the interview questions, even though they may cover the aspects of the questions asked in their daily work. Therefore, it may be difficult for participants to give high quality answers. In the process of the interview, the participant will constantly ask questions about difficult vocabulary, which can make the interview take longer. In response to this feedback, an explanation of specialized vocabulary was added to the interview section. However, it was not guaranteed that participants would understand all the vocabulary, so it was emphasized at the beginning of the interview that participants could ask questions at any time if they did not understand something.

The second tester thought the interview process was too complicated. It would take too much time to complete a full interview, but the participants were from different medical equipment companies and they might not have enough time to complete the whole interview. Therefore, the entire interview process needs to be simplified in order to reduce the interview time. This participant suggested using a combination of survey questions and interviews instead of a single participant format. The survey questions could be completed at any time, while the interview questions could be flexible depending on the questionnaire completed by the participant. The interviewer suggested that the first part of the question on the importance of enablers and vulnerability could now be completed in the form of a questionnaire. It was also suggested that a questionnaire with a name could be added so that it would be clear who had answered the questionnaire. Thus, by completing the questionnaire, participants would have a preliminary understanding of the interview and could improve the efficiency of the second part of the interview, which could help participants save some interview time.

Besides the testers' feedback, during the pretest, we also found some problems that we might encounter during the interview. Through pretesting, it was difficult to fix the length of time we interviewed. Because the interviews were highly flexible, participants' insights into supply chain resilience varied, and testers who knew more about resilience had more interaction with the interviewer, which would lead to longer interviews. In addition, participants who did not have a clear understanding of specialized concepts needed to be asked questions to help them understand the questions, and too much explanation would also increase the time of the interview. Therefore, if the actual interview is provided by the participant with a short interview time, then it may not be possible to conduct a complete interview. This requires the interviewer to be flexible and to control the pace of the interview.

5.3. Improve the interview questions

Based on feedback from the test participants, the initial design of the interview questions was refined for the purpose of being used to test the framework, and the improved interview questions can be viewed in Appendix B. In order to test the framework more efficiently. We adopted the suggestions of the testers and the new process will take the form of a combination of questionnaires and interviews. The first part of the questions for interviewing the importance of enablers and vulnerabilities will be in the form of a questionnaire. Data on the importance of enablers and vulnerabilities will be collected by using single-choice questions. There are three options for importance, A is very important, B is important, and C is not important. The questionnaire will be in the form of real names as it will be used for the second part of the interview. However, participants will be assured that the names will only be used to complete the second part of the interview and will not be revealed in the study. In addition, based on feedback from test participants that the interview questions were difficult to understand, more detailed explanations were added to the technical vocabulary in the interview questions so that participants could better understand the questions. Also, for participants to better understand the test questions, we provided a definition of supply

chain resilience and the designed supply chain framework in the questionnaire. Finally, it is worth noting that the interviewer needs to strictly control the pace of the interview. In order to ensure that the interview can be completed within the limited time, the interviewer may need to control the participants' responses and avoid participants discussing too much content that is not very relevant to the questions.

6 Testing the resilience framework

6.1. Data collection

A total of 15 supply chain professionals from 5 medical device companies were sent interview invitation emails for this study. A total of 10 people responded and completed the questionnaire, of which a total of 7 people from 4 different medical device companies accepted the invitation to be interviewed. Four of them are from company A, and the remaining three are from other different companies. The detailed information of the 7 participants is shown in Table10.

Table 10 The information of 7 participants

No.	Position	Background
A1	Sourcing manager	Company A is the parent company of several medical technology companies, headquartered in Germany. The Shanghai company is responsible for the Asia-Pacific region and the participants work in the Shanghai company.
A2	Sourcing specialist	Company A is the parent company of several medical technology companies, headquartered in Germany. The Shanghai company is responsible for the Asia-Pacific region and the participants work in the Shanghai company.
A3	Sourcing specialist	Company A is the parent company of several medical technology companies, headquartered in Germany. The Shanghai company is responsible for the Asia-Pacific region and the participants work in the Shanghai company. A3 worked for company A for about 2 years.
A4	After-sales supply chain department manager	Company A is the parent company of several medical technology companies, headquartered in Germany. The Shanghai company is responsible for the Asia-Pacific region and the participants work in the Shanghai company.
B1	General Manager	Company B is located in China and is a private medical device company.
C1	Logistics specialist	Company C is a U.S. medical equipment company. It is a new company that was separated from a larger U.S. medical equipment company. It is a new company. The Shanghai company is responsible for the Asia Pacific region. The participant works in the Shanghai company. C1 worked for company C for about 1 year.
D1	General Manager - supply chain	Company D is a small private medical equipment company in China. The company has import and export business, and has a professional after-sales team.

The questionnaire was used to understand the importance of enablers and vulnerabilities in the supply chain resilience framework. The questionnaire categorized each element into three levels of importance, very important, important, and unimportant. In addition, the questionnaire was used to help shorten the interview time and only the factors selected as very important were asked to the interviewees. 10 questionnaires were administered, 7 from company A and the remaining 3 from companies B, C and D. The detailed data collected from the questionnaires can be found in the appendix.

The semi-structured interviews were conducted online and ranged from 30 to 65 minutes in length. Before the interview, each participant was asked if he/she would agree to the recording of the interview, and consent was sought from each participant. The recordings were transcribed and identifying information was rewritten. During the consent process, participants were informed that their participation was voluntary and that their specific information would not be disclosed in the study results, but information about the medical device company they worked for would be presented. All participants provided verbal informed consent. At the end of the interviews, they were asked if the recordings could be transcribed and added to the appendix

of the paper, and all participants agreed that the interviews could be added to the appendix of the paper and that there was no confidential information that needed to be hidden. Appendix D shows the transcribed content of the recordings.

6.2. Analysing the questionnaire data

Table 11 shows the classification of the enablers based on the number of participants who chose the very important option. All participants identified agility, collaboration, and sharing information as very important; 90 percent identified trust as very important, and 80 percent identified adaptability as very important. The 70 percent category contained the most enablers: flexibility, innovation, risk management culture and visibility. The remaining enablers were considered to be very important by 60 percent of the participants. Overall, Table 11 shows that the selected enablers of supply chain resilience are recognized by the participants.

Table 11 Results of enablers- according to the number of choosing very important

	Number of choosing very important	**Enablers**
1	10	Collaboration, sharing information, Agility
2	9	Trust
3	8	Adaptability
4	7	Flexibility, Innovation, Risk management culture, Visibility
5	6	Redundancy, leadership,

Table 12 shows the specific choices made by the different participants. A represents very important, B represents important, and C represents unimportant. The analysis leads to the following proposition.

- Proposition 1: Different positions in the same company may have different perceptions of the importance of enablers.

  Table 12 shows that all the participants' choices were very important or important, except for three participants who thought that redundancy was not important and participant D1 who thought that visibility was not important. By analysing the jobs of the three participants who chose redundancy as unimportant, it was found that only these three participants (A7, B1, D1) were the main leaders of their sectors. They are responsible for the leadership and management of the whole sector, and they are not responsible for a specific task. They think more from an overall perspective and need to understand the whole work process. Therefore, we believe that different positions in the supply chain can lead to different perceptions of the importance of the enablers among the participants.

- Proposition 2: Different company backgrounds can cause differences in the perceived importance of enablers.

  By exploring the company backgrounds of these three participants, it was found that participants D1 and B1 participants were from small and medium-sized private companies in China, while participant A1 came from a Shanghai branch with a foreign background. Although participant A7 has a different company background from participants D1 and B1, A7 stated in the interview that he did not know much about supply chain resilience. Therefore, even though participant A7 was one of the participants who chose the option of not important, I think it is still possible to make the proposition that different company backgrounds may be responsible for the differences in the perceived importance of enablers.

- Proposition 3: Work experience will affect the perception of enablers.

  Table 12 shows that there are 7 participants from company A. Their answers to the questionnaire are relatively similar, but it can still be seen that the answers of participants A3 and A7 are different from the other 5 participants. Except for two participants, participants A3 and A7, the rest of the participants considered all the given enablers to be very important. According to Proposition 2, it can be assumed that participant A7's perception of what is important differs significantly from the other participants because of the different positions from the others. Participant A3 entered the company for a shorter period of time than the others and has less work experience. In addition, it was found in the interview

that there were some supply chain situations that participant A3 was not very clear about because of less work experience. So, proposition 3 was proposed that work experience also affects participants' perceptions of the importance of enablers.

Table 12 The choices about enablers for all participants

Participant	Collaboration	Visibility	Sharing information	Trust	Risk management culture	Leadership	Redundancy	Innovation	Flexibility	Agility	Adaptability
A1	A	A	A	A	A	A	A	A	A	A	A
A2	A	A	A	A	A	A	A	A	A	A	A
A3	A	B	A	A	B	B	A	B	A	A	A
A4	A	A	A	A	A	A	A	A	A	A	A
A5	A	A	A	A	A	A	A	A	A	A	A
A6	A	A	A	A	A	A	A	A	A	A	A
A7	A	B	A	A	B	B	C	B	B	A	B
B1	A	A	A	A	A	B	C	A	B	A	A
C1	A	B	A	B	B	B	B	B	B	A	B
D1	A	C	A	A	A	A	C	A	A	A	A
A	10	6	10	9	7	6	6	7	7	10	8
B	0	3	0	1	3	4	1	3	3	0	2
C	0	1	0	0	0	0	3	0	0	0	0

In contrast to the enablers, there is a greater variation in the perceived importance of vulnerabilities. Specific data on choices can be found in Appendix C. Table 13 shows that 70 percent of the participants considered transportation efficiency to be very important, and Table 14 shows that only transportation efficiency was considered unimportant by none of the participants. Only two participants considered turbulence to be very important. For the remaining vulnerabilities, 50 percent of the participants chose the very important option.

- Proposition 4: The medical equipment after-sales service supply chain values customer satisfaction very highly, which influences the perception of vulnerability.

  In the interview, participants from the medical equipment after-sales service supply chain described the characteristics of the supply chain. The after-sales service supply chain takes customer satisfaction very seriously, and the arrival of orders on time will affect the satisfaction of customers in the supply chain. Therefore, most of the participants agreed that transportation efficiency is very important, and if transportation is affected, orders that do not arrive on time will reduce customer satisfaction.

- Proposition 5: The probability of occurrence of vulnerability affects participants' choice of the importance of vulnerability.

  Among all the vulnerabilities, only turbulence was the least important. Only 2 participants considered turbulence to be very important, 6 participants regarded it to be important, and the remaining 2 thought it to be unimportant. The interview revealed that some participants thought that the probability of occurrence of turbulence was low, and they did not often meet supply chain disruptions due to turbulence in their daily work, so they did not think it was very important.

- Proposition 6: Different positions will affect the perception of vulnerability.

  According to Table 14, we can find a total of 4 participants (A3, A7, B1, D1) who considered some of the vulnerabilities in the framework to be unimportant in the questionnaire. More participants made unimportant choices about vulnerability compared to the data on propulsion, and participant A3 considered all of the propulsions in the questionnaire as very important or important. By analysing the positions of the four participants, all the remaining participants except A3 are the main responsible of the sector, which has been mentioned in Proposition 1. Therefore, we propose Proposition 6: Different positions have an impact on the perceived importance of the vulnerabilities.

Table 13 Results of vulnerabilities- according to the number of choosing very important

Order	Number of choosing very important	Vulnerabilities
1	7	Transportation efficiency
2	5	Supplier disruptions, Organizational Complexity, External pressures
3	2	Turbulence

Table 14 The choices about vulnerabities for all participants

Participant	Supplier disruptions	Organizational Complexity	External pressures	Transportation efficiency	Turbulence
A1	A	A	A	A	B
A2	B	B	A	A	B
A3	A	B	C	A	B
A4	B	B	B	B	B
A5	A	A	A	A	A
A6	A	A	A	A	A
A7	C	B	C	B	B
B1	C	A	B	A	C
C1	A	A	B	B	B
D1	B	C	A	A	C
A	5	5	5	7	2
B	3	4	3	3	6
C	2	1	2	0	2

6.3. Analysing the interview data

In the interviews, they were asked primarily about their perceptions of the enablers and vulnerabilities measures in the supply chain resilience framework. In addition, the questions that the participants were asked to answer were flexibly adjusted based on the results of their questionnaire. In the following, the information gathered from the interviews is analysed.

6.3.1. Analysing the enablers

Agility, information sharing and collaboration

The questionnaire results showed that all participants agreed that agility, information sharing, and collaboration are very important. Participant A5 said that agility has become very important especially in recent years, and companies often emphasize agility in their supply chains. In addition, participants A1 and C1 thought that agility required the supply chain to have a predictive capability. As a result, certain arrangements can be made for what is predicted. When something does happen, the response time can be reduced by taking timely action. For example, participant C1 said that the company located in China needed to assist the head office with a business of exporting packaging from China to the U.S. and Europe due to a factory move of the packaging company. The price of shipping by sea was too high, so the Chinese company finally chose a relatively cheap shipping company through inquiry and comparison. However, due to the recent instability of the ocean freight market and the high demand for shipping positions. It leads to the problem of delay even though the company is now not considering the shipping price.

We believe that this example illustrates that the supply chain does not anticipate possible situations, which leads to a failure to react in a timely manner when problems arise. However, whether there is a relationship

between predictive capability is and agility, we need further confirmation through more research. Because the participants only presented such an idea here, we cannot conclude that there is a link between prediction ability and agility without validation.

For the indicators used to measure agility, a total of three are proposed in this paper. However, different participants have different views on the indicators used to measure agility. There was some controversy about whether the time to detect a threat could be used to measure agility. Participant A2 believes that threats are irrelevant to agility and think it is not reasonable to use the time to detect threats to measure agility.

The results of the questionnaire showed that all participants agreed that collaboration was very important. Participant A7 noted that when there is a problem in the supply chain, all people from top to down need to work in the same direction, so collaboration is considered very important. Participants A1 and C1 also discussed the importance of collaboration, from both internal and external perspectives, in performing normal work and helping to return the supply chain to a balanced state. This is because neither processes nor organizations simply require someone to do one thing. For example, the process in Company A is very segmented. If a spare part is to be provided, the standard process is that it needs to be returned for repair, and then sent back after it is fixed. So, there must be many departments involved in this part, and as long as there is a problem in the collaboration of one of them, the whole supply chain will react.

In the interviews, all participants who answered questions about collaboration agreed that the efficiency of communication was essential to measure supply chain collaboration. However, different participants had different opinions on how to measure communication efficiency quantitatively. Participant C1 believed that the average response time to emails could be used to measure communication efficiency and that responding to emails on time indicated more efficient communication. However, participant A5 had a different view that there are other forms of daily communication, such as meetings and phone calls, and that email response time cannot fully describe the efficiency of communication. Participant A7 suggested that the effectiveness of meetings could be used to indicate the efficiency of communication.

Furthermore, all participants had questions about the indicator of collaborative forecasting, which they could not understand the meaning of this indicator. Although after explanation, although participant A7 thought this indicator had some meaning, it was actually not common in actual work. Participant B1 also gave other indicators that could be used to measure collaboration and suggested that the partnership between the supplier and the company may affect the efficiency of collaboration.

In terms of forecasting, sharing information is very important and participant A1 mentioned in the interview that a lot of information is needed when building a supply chain forecasting model. This participant also mentioned that in terms of risk, sharing information was also considered very important. For example, if a supplier discovers some risk in market supply, it can share information with the medical equipment company, which can help the company solve the problem quickly and thus be able to reduce the risk. In addition, participant A7 pointed out that sharing information is considered the basis for collaboration, which allows the supply chain to collaborate and solve problems in the supply chain quickly after problems occur. External sharing information can help the supply chain avoid supply disruptions due to increased demand. Participant A1 mentioned that if the company believes that the demand for a product is going to increase, then the company will place orders with the supplier or share the news of increased orders with the supplier promptly, which can avoid a sudden increase in demand and zero inventory of the product.

Through the interviews, we found that participants had different views on the indicators to measure information sharing. Some participants felt that information sharing could not be measured by the effectiveness of inventory management. Because participant A2 believed that the efficiency of inventory management is also influenced by other factors and participant C1 indicated that there is no inevitability between the efficiency of inventory management and information sharing. However, participant B1 believed that shared information is extremely helpful for inventory management and can be used as an indicator.

In addition, for the indicator of the probability of uncertainty, participant B1 was not sure about the validity of this in practical application. The correctness of information was brought up by most of the participants in the interviews as a way to measure sharing information. Participant C1 mentioned in the interview that the

information about the weight of the product in the company's system was incorrect, thus affecting the inspection of the product by customs, because the actual weight did not serve the bill of goods and was subject to customs inspection. Therefore, sharing the correct information is considered very important. In addition, participant A1 also mentioned that with the explosion of information, it is also important that the right people receive the right information. So, the correctness of information may also be considered from this aspect.

Trust

In general, trust was considered to be very important by a large number of participants, nine in total. Participant A7 said that trust is related to both cooperation and information sharing, so trust is equally very important. The indicators chosen to measure trust were considered to be applicable in practice. However, the wording of some of the indicators needs to be changed. Participant B1 suggested that sharing confidential information can be changed to sharing professional information in the supplier industry. Because confidential information may exist as commercial secrets, sharing confidential information is not appropriate from this perspective if commercial secrets are considered. In addition, participants provided some other indicators that can be used to measure trust. Participant A2 mentioned that supplier partner complaint rates can be used to measure trust. Because of the more complaints about the partner, the more questions about the cooperation with the partner, then the lower the trust with the partner. The frequency of business with a partner can also be used to measure trust. If the frequency of business with the partner is high, then it means that the trust in the partner is higher, because the trust is willing to enter more cooperation with the partner.

Adaptability

Next is adaptability, which a total of eight participants considered to be very important. Participant A1 considered that adaptability can help the supply chain to adopt some operations that are against the daily standardization to adapt to the external situation because the external changes affect the supply chain, and adaptability can adjust the supply chain to the external changes in time. Therefore, adaptability is considered to be very important for enhancing supply chain resilience. For example, the resource in the next level of the market is currently in a very scarce situation, and there is no way for the standard process at this time to adapt to the daily pattern of making plans. Under normal circumstances sourcing can be based on lead time to suppliers to place orders, suppliers regularly shipped. If you need to rush the goods, the supplier can expedite the additional goods. However, the scarcity of the chip market now makes it necessary to change the model of the program, as suppliers now require the company to provide a firm's forecasted demand or to place a direct purchase order, which is different from the daily standardized operation.

In addition, when discussing issues related to adaptability, it was found that not all participants were able to clearly distinguish adaptability, agility， and flexibility. Therefore, it is particularly important to elaborate the relationship between the three enablers in the framework. Different participants gave different answers to the indicator of speed of repositioning requirements. In addition, participant B1 suggested that adaptability could be measured by judging whether there is a standard process versus a non-standard process and that both sets of processes could be used. If the company would have a more than standard process, colleagues have another non-standard process. If changes are encountered, the non-standard process can be used, which shows that the supply chain can adapt to changes quickly. Finally, participant B1 also believed that adaptability can be considered in terms of innovation, and that if there is the ability to continuously innovate then this indicates that the supply chain can better adapt to change.

Visibility, risk management culture, innovation and flexibility

The results of the survey showed that 70 percent of the participants considered visibility, risk management culture, innovation and flexibility to be very important. However, one participant felt that visibility was not important, which is different from the other enablers in this section. Since the participant was only asked the reason for choosing very important in the interview, it is not known why this participant did not think visibility was important, and this reason can be explored in future studies. When interviewed about issues related to visibility, participant C1 inevitably mentioned indicators of shared information, the sharing of which affects

access to information, and therefore this sharing of information was considered necessary to achieve visibility. For visibility measures, participant B1 said that the forecast error indicator is not considered an accurate measure of visibility because forecast error is influenced not only by visibility but also by the accuracy of the information.

In terms of risk management culture, some medical equipment companies have created a special risk medication group or team. In the event of a risky situation, such as a hurricane in the United States, the risk medication team will anticipate the risk in a timely manner. Participant A1 stated that the strengthening of the company's risk management culture indicates an awareness of supply chain risks, so the company can reduce the impact of risks by anticipating them and reacting to them in a timely manner. When risk comes, the supply chain can still operate normally. Therefore, risk management culture is considered as an important enabler for enhancing supply chain resilience. For example, during the Covid-19 epidemic, countries such as Spain and Italy also took measures to lock down their cities. At this point, it was necessary for the company to communicate with suppliers and ask in advance if there would be any supply issues due to this city lockdown. If there is a supply problem, through communication the company can take action in advance. Some suppliers may not be aware of possible supply shortage problems, then by medical equipment companies trigger their suppliers, then suppliers who may have problems can take measures in advance.

For the measurement indicator of risk management culture, participant B1 thought that it is not suitable to measure the risk management culture in the supply chain by the reward and punishment mechanism about the risk. This is because this is not considered valid as a KPI to assess. If in this position it is necessary to have a certain positive risk awareness a judgment about the position to the next step.

The analysis from participant A1 showed that innovation can continuously improve the supply chain and make it more adaptable to changes in the environment, thus influencing the resilience of the supply chain. In the interview, the participant A1 indicated that there is a platform for innovation in the company's daily work and that innovation in the supply chain is particularly reflected in the improvement of processes. For example, the standard for after-sales medical equipment spare parts transportation is very high, so clear logistics information that can be checked in a timely manner is very important. The participant from company A said that the company also has innovations about the last mile and discussed how to get through the last mile. Through innovation, the supply chain can be largely improved, and thus the whole capability of the supply chain is enhanced. The probability of the supply chain continuing to operate properly is increased when disruptions to the supply chain are encountered. Therefore, participants considered innovation as a very important enabler for enhancing supply chain resilience.

In addition, participant B1 mentioned that the development of the country or the medical equipment industry is always changing. Therefore, in order to make the medical equipment after-sales service supply chain adaptable to the environment and maintain a stable state, it is necessary for the supply chain to innovate. This is why participants consider innovation to be a very important enabler.

For the relevant indicators to measure innovation, participant A5 said that service innovation, was too broad and difficult to measure supply chain innovation in practical application. Therefore, participants suggested some indicators that can be used to measure innovation quantitatively and can be better applied in practice. In terms of the company's innovation culture, participant A5 suggested that the company can provide training related to innovation or often organize meetings to exchange leading information in the industry. The more activities held each year, then the more attention the company pays to innovation.

In addition, participant A5 thought that number of supply chain innovation ideas presented on the innovation platform can be used to measure supply chain innovation. The more ideas about innovation, the more the company as a whole is involved in innovation and the higher the level of supply chain innovation. Furthermore, participant A1 considered that the presence of a platform within the company that promotes innovation can also measure supply chain innovation. If there is an innovation platform within the company, it indicates that the company is taking steps to promote innovation and that innovation is valued within the company.

When flexibility was mentioned in the interviews, participant A1 and participant A5 talked about agility or adaptability at the same time, and considered the three enablers to be similar, making it easy to confuse the three enablers. Participant A1 stated that supply chain agility helps supply chain organizations to adjust their plans to actual conditions at any time, so it is a feature that must be considered in the process of adapting an organization's structured processes to market changes. Participant 1 also suggested that if agility is improved, then flexibility will also increase, but it is worth noting that increased agility does not mean that flexibility can be improved immediately. Because if the problem is very complex, even if action is taken quickly, it may still end up taking a lot of time to coordinate a solution. But if the supply chain organization does not improve agility, then there will be no follow-up improvement in flexibility.

For measuring flexibility, participants in the interviews suggested other indicators that could be used to measure flexibility in addition to the ones already suggested. Participant A2 pointed out that on-time delivery rate means that orders are sent out according to the specified time, but on-time delivery rate does not mean that customers always receive their orders on time. This is because a customer's ability to sign off on an order on time is affected not only by delivery time but also by shipping efficiency. Therefore, the on-time arrival rate of orders is considered to measure the flexibility of the supply chain as well.

In addition, participant A1 suggested the adequacy of capital is used as an indicator of flexibility. Because the after-sales service supply chain is different from the production supply chain, which has a monthly demand for customer orders and therefore can forecast in advance, the after-sales service supply chain, however, does not have a monthly demand for orders, so it usually does not forecast in advance but orders spare parts based on historical data. If the customer's demand sometimes increases suddenly, then the prepared inventory will not be able to meet the customer's demand. Therefore, to solve this problem, flexibility needs to be improved by investing a lot of money. This is because increased stocking can increase the flexibility of the after-sales supply chain. So, without a large amount of money to support, the flexibility of the after-sales service supply chain will be weaker.

Redundancy and leadership

The final category was redundancy and leadership, with 60% of the participants considering these two enablers to be very important. Unlike any other enabler, a total of three participants did not consider redundancy to be important. Redundancy in the supply chain refers to maintaining more inventory or production capacity in the supply chain than is normally required. However, redundancy is considered to be against the goal of creating an efficient business. In order to achieve the goal of redundancy, companies must pay for redundant inventory, capacity and workers. In addition, this overuse may lead to sloppy operations, reduced quality, and significantly higher costs. As a result, some participants indicated in the questionnaire that redundancy is not important to supply chain resilience.

However, participant A1 said that the medical equipment after-sales supply chain is considered unique, and professionals who are familiar with the business believe that redundancy brings a level of security to the medical equipment after-sales supply chain. Because spare parts used as after-sales are difficult to forecast, sourcing staff often rely on historical data for spare parts. Demand in the after-sales service chain is unstable, so redundancy can help avoid supply disruptions caused by excessive demand fluctuations. Participant A1 also mentioned that medical equipment companies must aim primarily at their customers' markets, so service performance and delivery capability are very important indicators, and they directly affect the company's future business development with customers. Therefore, the supply chain about medical equipment spare parts needs to be shipped as soon as the customer makes an order, rather than ordering after the customer has placed an order. In addition, the supply chain market is now unstable, so for the medical equipment after-sales service supply chain, stocking up is a good solution. This can reduce the impact on the supply chain due to market instability. Therefore, redundancy is considered to be an important enabler for enhancing supply chain resilience.

Stock level is an indicator used to measure redundancy. However, by analysing interviews, we know from participant A2 that the turnover rate is a common indicator of redundancy in daily work. Stock turnover rate is the number of times goods are turned over in a given period of time. It is an indicator of how fast or slow the inventory turnover is. If the turnover rate is high, then the redundancy is low. For another indicator of measurement, warehouses and facilities spread, different participants had different viewpoints, and

participant A2 who disagreed with the use of this indicator, believed that warehouse and facility distribution was irrelevant to supply chain redundancy.

For leadership, participant A5 believed that leadership is the foundation for successful implementation of solutions and projects, because all decisions or solutions that are intended to be implemented ultimately require leadership to make the final decision. If there is a lack of effective leadership in the supply chain, then many things will be in a state of limbo Otherwise, it will be as the participant A5 said no matter how good the ideas are, they will hardly become reality without the decision and support of the leaders. Therefore, when supply chain problems occur, good leadership can help the supply chain continue to operate, or recover to a stable state as soon as possible. Good leadership is the foundation for smooth implementation of solutions, which is why in the interviews, leadership was considered as important for enhancing the resilience of the supply chain.

In addition, in the interviews, participant A1 indicated that leadership measures can be considered in both individual and organizational aspects. Individual leadership is demonstrated by whether the individual is proactive in seeking solutions when faced with difficulties. This is done by discussing with others the pros and cons of the proposed solution and discussing its feasibility to solve the problem in a timely manner. From an organizational perspective, participant thought that leadership requires a core strength. When a member at a lower level or within a department experiences some difficulties, the manager is able to figure out how to coordinate resources from a higher level to solve the problem. Finally, participant 1 felt that4 leadership is related to collaboration. When a problem arises, the leader needs to be able to work with other departments to solve the problem in a smooth and timely manner. The relationship between leadership and collaboration is not captured in the framework, and we believe that further exploration of the relationship between leadership and collaboration is needed.

6.3.2. Analysing the vulnerability

Transportation efficiency

According to Table 13, it can be seen that the highest number of participants (7 participants in total) considered transportation efficiency as a very important vulnerability. Transportation efficiency was the only one of the five vulnerabilities where participants did not choose an unimportant option. This is because participant A1 said that customer satisfaction is a very important performance in the medical equipment after-sales service supply chain. The performance of customer satisfaction is influenced by the transportation efficiency of orders, so transportation efficiency would be considered as a very important vulnerability in the medical equipment after-sales service supply chain. We learned from participant A2 that as the number of direct flights dropped sharply, especially during the Covid-19 epidemic, companies had to choose other routes that required connecting flights, which greatly extended the transportation time and could even lead to delays of orders.

The interviews revealed that different participants had different opinions on whether the length of customs inspection time can be used to measure the efficiency of transportation. Participant A2 believed that the time of customs clearance is impressed by various factors, and sometimes there are problems with the customs declaration that lead to longer inspection time. Therefore, the length of customs clearance is uncertain, and the increase in customs inspection time will lead to an increase in the overall transportation time. However, participant B1 said that there is a fixed length of customs inspection and therefore using this indicator to measure the efficiency of transportation is not valid.

In addition to the two indicators already given, participant A2 suggested that whether it is the optimal transport route can also be used to measure transport efficiency. This is because the most optimal transport routes can reduce the time of transport and even save resources. For example, most of the transportation routes for air during the covid-19 epidemic require multiple connections. If there are less connections, the route is more efficient and the transportation time will be reduced. In addition, participant A2 also mentioned that the number of orders will affect the efficiency of transportation. Smaller orders are easier to ship quickly because they can be put together with other orders for one trip. If the size of the goods is too large and heavy, they may need to be transported separately, and it will take time to reschedule. The greater the carrier's capacity, the more efficient the transportation will be. Finally, participant B1 thought that the

completeness of the product to customer sign-off is also considered to be a measure of transportation efficiency. Because products may be damaged during transportation, if there is a high probability of customers receiving a damaged order, then this indicates that transportation efficiency needs to be improved.

Organizational complexity, external pressures and supplier disruptions

The results of the questionnaire show that half of the participants consider organizational complexity, external pressures, and supplier disruptions to be very important. For these vulnerabilities, some participants also thought they were not important for enhancing supply chain resilience. Here, however, we did not ask every participant about the reasons for this choice due to the interview conditions.

Different participants had different thoughts about the complexity of the organizational structure. In fact, participant A2 was sceptical about whether the complexity of the organizational structure was a vulnerability. Because for the too single organizational structure, once this supply chain has problems, then it is difficult for the organization to respond in time. However, participant A2 said if the organizational structure is a little more complex than a single organizational structure, the organizational structure is that there will be cross lines, then when there is a disruption in one part of the supply chain, the other parts of the organizational structure can give timely help. In conclusion, participant A2 proposed that organizational complexity is a double-edged sword. The disadvantage is that too many levels of an organization make information transfer difficult and can have a significant impact when problems arise.

As for indicators of organizational complexity, participants thought it was appropriate to measure complexity in terms of how many layers the organization chart has. However, the indicator about the number of people involved in a project decision could be improved. Because participant B1 indicated that there would be key people involved in a decision as well as non-key people. The non-key people may not be as important, and they can be streamlined. So, in the whole process, if you have less non-critical people, your whole process going up will also be more and more the better. Therefore, when measuring the number of participants in a decision-making process, the number of non-critical people is mainly counted. In addition, the participants also suggested that the business overlap between departments can be used to measure the complexity of the organization. Because some of the company's departments more or less overlap if the division of responsibilities between them is not clear, it may have an impact on the whole organization.

In the interviews, the discussion of external pressures and supplier disruption was very lacking due to time limitations. For supplier disruptions, participants A1 and A7 mentioned that the shortage in the market for electronic components has caused problems with the supply of electronic components. If it is not handled in a timely manner, the company will face supply disruptions. The sourcing of the company needs to communicate with the suppliers to actively deal with this problem. Therefore, the participants consider it important to take timely action to reduce the impact of vulnerability on the supply chain. When answering questions related to external pressure, participants mentioned retaliatory tariffs in the case of the US-China trade war, which is the new policy, and this trade war has had an impact on the supply chain of related industries, so participants believe that external pressure is also very important vulnerability.

Turbulence

The results of the questionnaire showed that only two participants considered turbulence to be a very important vulnerability. From the interviews, we learned that the participants thought that although the consequences of turbulence are very serious when it occurs, the probability of serious turbulence occurring is not very high. Therefore, most of the participants indicated that turbulence was not very important.

7 Discussion

By analysing the results of the resilience framework test, the improved supply chain resilience framework can be viewed in Figure 5. The questionnaire section of the test investigated the importance of enablers and vulnerabilities in the supply chain resilience framework, and the improved resilience framework categorizes enablers and vulnerabilities based on the number of choices that are very important in each of the enablers and vulnerabilities of the test. An improved resilience framework that categorizes enablers and vulnerabilities is easier for professionals to use to enhance supply chain resilience. With limited resources, professionals can maximize or minimize the most important enablers and vulnerabilities first, which we believe can be more effective in enhancing the resilience of the supply chain. The questionnaire categorized the level of importance into 3 levels, very important, important, and unimportant. This makes the analysis of the questionnaire results easy to operate, and the results are analysed based on the number of participants who selected the very important option. However, we believe that the classification of the questionnaire for importance is rather crude, so the classification in the resilience framework can be further refined in the future. If only a limited number of drivers can be analysed, then by using the resilience framework of an improved supply chain, professionals can choose information sharing, trust, and collaboration. This is because analysing these enablers will bring better results than analysing the other enablers.

When designing the supply resilience framework, we pointed out the relationship among agility, adaptability and flexibility through literature study (see Section 4.3). The relationships among trust, collaboration, information sharing, and visibility were also collated and can be viewed in Figure 5. In analysing the results of the interviews, we found that when asked questions about adaptability or flexibility, participants gave the idea that flexibility was more similar to agility, which is right in line with the results given by participant A5 in the interview. We think that not everyone in the medical equipment after-sales supply chain industry has a clear distinction among adaptability, flexibility and agility. It is easy for them to mix these three enablers and affect the practical application of the supply chain resilience framework. If the relationships among enablers are explored, the supply chain resilience framework that is designed will be clearer. When professionals use the supply chain resilience framework, confusion about the enablers is less likely to lead to failure in enhancing supply chain resilience.

By examining the content of the interviews, we found that participants mentioned the relationship among agility, adaptability, and flexibility. Since these three enablers were difficult to distinguish for most participants, participant D1 pointed out that flexibility and agility were similar because they both express the ability to quickly solve problems in the supply chain. The previous chapter discussed that if agility is improved, flexibility will increase along with it. If agility is not improved, then it is difficult to improve agility. But the relationship in Figure 5 indicates that agility is influenced by flexibility and that increased flexibility improves agility. This is different from the results obtained in the interviews. However, there was no indication for this relationship in all the current literature that increased agility and thus flexibility was affected. The possible reason for this result presented in the interviews is that the participants were based on the characteristics of the medical equipment after-sales service supply chain and therefore would differ from the results obtained from the literature. However, the exploration of the relationship between agility and flexibility requires an in-depth study through the supply chain to get the actual working situation, and the conclusion of the relationship should be given to the results of the study obtained in practice. In addition, in the analysis in the previous chapter, it was mentioned that flexibility is a characteristic that must be considered in order to improve adaptability. This is consistent with the relationships described in Figure 5 where flexibility can influence adaptability.

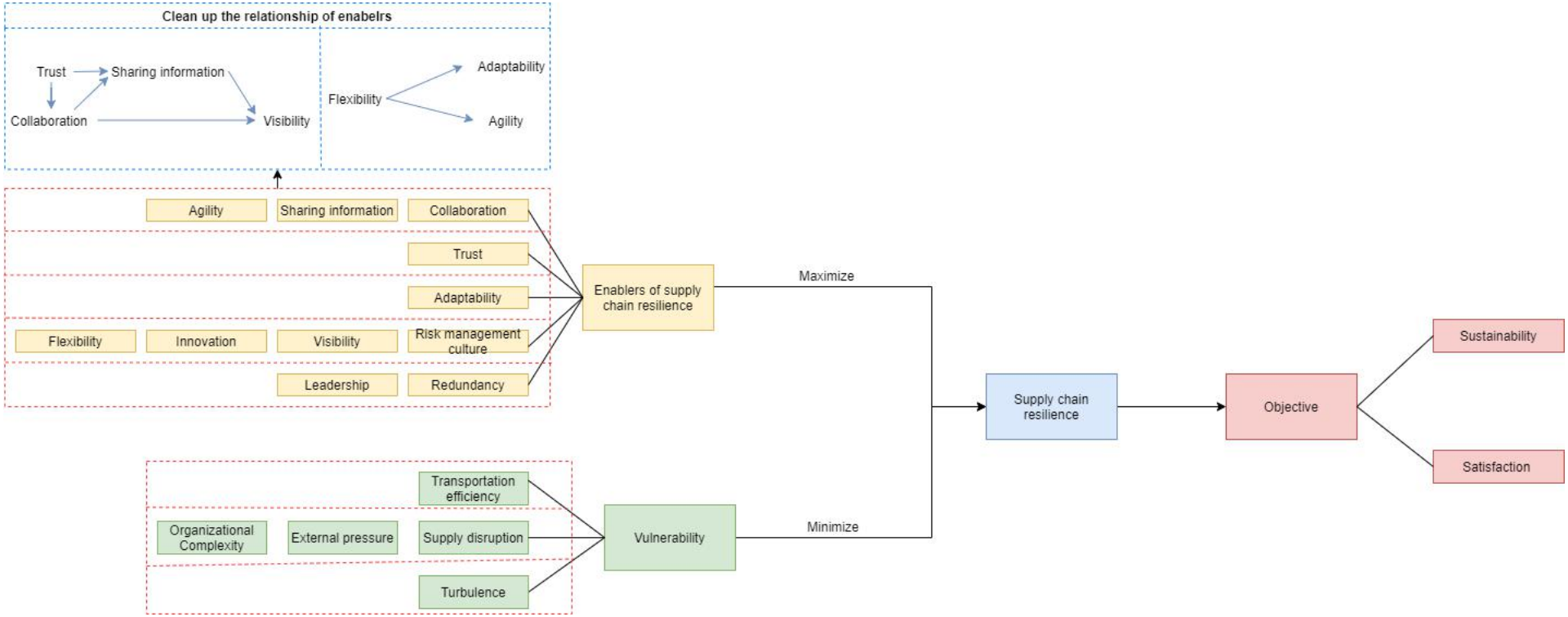

Figure 5 Improved supply chain resilience framework

The relationships among trust, collaboration, information sharing, and visibility were also mentioned several times in the interviews. During the interviews, participant A7 indicated that collaboration is needed to be achieved based on a foundation of trust in each other, and then information is shared with all staff based on collaboration and trust. This is consistent with the relationship obtained through literature research in section 4.3. In analysing the interviews about visibility questions, we found that information sharing is inevitably mentioned, and visibility cannot be improved without the prerequisite of shared information, which was also mentioned by participant A5 when they answered visibility questions in the interviews. This is also consistent with the relationship between shared information and visibility obtained from the literature study in Figure 5. However, the relationship between collaboration and visibility, shown in Figure 5, was not mentioned by the participants in the interviews. Whether collaboration and visibility are interrelated in actual supply chain operations can be further tested in future research.

Finally, we will discuss the indicators used to measure enablers and vulnerabilities. Through the interviews, we found that some of the enablers and vulnerabilities designed before the test could not be applied in practice and that these indicators were only "paper-based". Therefore, based on the results of the interviews, we improved the indicators of enabler and vulnerability. The updated indicators are more easily operationalized in practice to measure enablers and vulnerabilities. The improved indicators are shown in Table 15 and Table 16.

Through the interviews, we found that the frequency of collaborative forecasting was difficult for the participants to understand and they often questioned the indicator. Based on the feedback given by the participants, we think that although this indicator is meaningful for measuring collaboration, participants usually do not deliberately consider collaborative prediction in their daily work. Therefore, we concluded that it is not appropriate to use this indicator to measure collaboration.

Familiarity with collaborators is a new indicator, which was suggested by participant B1 in the interviews. We believe that this indicator can properly measure collaboration, because if you collaborate with a supplier who has a high degree of familiarity, then it is easier for the supplier to predict the customer's requirements in advance, so the communication cost will be lower. But if you collaborate with a supplier who has fewer business dealings, then the degree of collaboration will be inefficient in all aspects. So, the degree of collaboration with the partner can be measured by the degree of familiarity.

We learned from the interviews that using supplier delivery efficiency to measure collaboration is not appropriate. As mentioned by participant A5 in the interviews, the supplier delivery schedule has to be strictly in accordance with the signed contract, so the supplier delivery efficiency does not have a strong relationship with the later collaboration. Although collaboration can help to solve problems or bottlenecks quickly when the partner (customer or supplier) encounters them. However, this supply delivery efficiency is still not relevant, so this indicator cannot be used to measure supply chain collaboration.

For visibility, a total of four indicators were proposed in this framework. Only the forecast error indicator is controversial, and participant B1 suggested that the forecast error indicator is not considered to be very appropriate. We believe that the error in forecasting is affected not only by visibility, but also by the accuracy of the information and, more importantly, by the forecasting model. Therefore, forecast error was not considered appropriate for measuring visibility.

The results of the interviews indicated that sharing information does help in inventory management. However, the efficiency of inventory management is not only affected by sharing information, but also by the efficiency of collaboration with other departments. Therefore, we suggest that it is inappropriate to use the efficiency of inventory management to measure information sharing in the supply chain.

Moreover, the interview results showed that participants 1, 3, 4, and 7 mentioned the accuracy of the information and illustrated its importance in sharing information. Therefore, the accuracy of the information can be used as a new indicator to measure sharing of information. The information needs to be delivered to the right person and the information shared needs to be correct, otherwise, this shared information will lose its meaning.

Participants pointed out that the stock turnover rate is usually used in daily work to measure redundancy, and if the turnover rate is high, it indicates a low level of redundancy. Stock turnover rate is also a redundancy indicator from the stock point of view. Stock level is an indicator that requires a reference value, and the amount of stock required to achieve redundancy varies for different spare parts, so the stock turnover rate is a more operational indicator. In addition, the stock turnover rate is a more commonly used indicator. Therefore, the stock turnover rate will replace stock level as an indicator.

In the first phase, a total of two indicators used to measure innovation were proposed in the designed supply chain resilience framework. Through the results of the interviews, we concluded that both indicators are descriptive and too broad to be used in practice. Therefore, both indicators will no longer be used to measure innovation in the updated indicators. Based on the results of the interviews, we proposed two new, more operational indicators to measure. The first one is considered in terms of company innovation culture. When a company's entire culture emphasizes innovation, the company will provide training on innovation or organize meetings to share leading information in the industry. So, you can measure innovation by the number of innovation-related events a company holds in a year. In addition, the number of supply chain innovation ideas that employees come up with in a year can also be used as an indicator, as these ideas can be quantified. However, not all ideas are adopted and realized, so the percentage of ideas adopted to the total ideas proposed is a more appropriate indicator of innovation.

Table 15 The improved indicators of the enablers

Enablers	Indicators
Collaboration	Degree of familiarity with partners
	Efficiency of communication
Visibility	Level of information technology
	Degree of information exchange
	Ease of acquiring the information
Sharing information	Accuracy of forecast
	Accuracy of information
	Probability of uncertainty
Trust	Time that the relationship lasts between the buyer or the seller
	Confidential information sharing
	Existence of mutually beneficial cooperation terms
Risk management culture	Incentive and punishment of risk management
	Level of knowledge of risk management
	Risk management culture training
Leadership	Number of resilience strategies or decisions
	Magnitude of supply chain resilience power
	Degree of leadership understanding of supply chain resilience
Redundancy	Stock turnover rate
	Warehouses and facilities spread
Innovation	Percentage of innovations adopted
	Number of supply chain innovations per year
Flexibility	Spare part-supplier rate
	Sufficiency of financial resources
	Rate of deliver on time
	Rate of on-time arrival
Agility	Time to respond
	Time to access relevant data
	Time to detect threats
Adaptability	Speed of re-routing the requirements
	Learning from experience

For the vulnerability section, only the indicators of transport efficiency were updated. Based on the results of the interviews, two new indicators to measure transport efficiency were finally added. The first one is about transportation routes. The optimal transportation route can save transportation time, and from the perspective of global transportation, the policies of different countries also have an impact on transportation

efficiency, so the optimal transportation route not only improves transportation efficiency but also reduces the problems caused by different policies. Therefore, the degree of optimization of transportation routes is used as a new indicator. The second one is about carriers. In the interviews, the participant A2 and B1 mentioned that the capacity of carriers will also affect the results of transportation. If the service level of the carriers is high, then the probability of transportation troubles is low. In addition, the different transport capacities of the carrier will also bring different results to transport efficiency. Therefore, the transport capacity of the carrier is another new indicator.

Table 16 The improved indicators of vulnerabilities

Vulnerabilities	Indicators
Supplier disruptions	Frequency of occurrence per type of event Level of the supplier reliability Number of suppliers per type of goods
Organizational Complexity	Number of the hierarchical layer of the organizational chart. Number of the decision makers involved in a project Number of the processes and rules
External pressures	Product sales volume Monitoring the political events Price fluctuations
Transportation efficiency	Degree of optimization of transportation routes Time of customs inspection Transport capacity of the carrier Number of the delayed transportation orders
Turbulence	(No indicators)

8 Conclusion and recommendation

In this thesis, we propose a supply chain resilience framework whose purpose is to help professionals enhance the resilience of medical equipment after-sales service supply chains. The framework specifies indicators for resilience enablers, and for vulnerabilities that can be used to assess and diagnose the present state of a medical equipment after-sales service supply chain: which potential enablers are still underdeveloped, and which vulnerabilities are high? Such assessment and diagnosis can enable decision makers in the supply chain to improve its resilience. This increased supply chain resilience allows the supply chain to operate as sustainably as possible even when experiencing trouble. This increased resilience can help the after-sales service supply chain operate efficiently and avoid medical equipment breakdowns that go unrepaired for long periods, which can lead to delays in diagnosing patients. For patients, time can be a life.

The main research question for this thesis was: "*How to assess the resilience of the after-sales service supply chain in the medical equipment industry?*". This paper answers this main research question through a mixed method approach and divides the entire research into two phases. At the end of the first phase, this paper obtained a conceptual framework for a resilient supply chain and identified indicators to measure the enablers and vulnerabilities in the framework. The framework was used to enhance supply chain resilience and was applied to the medical equipment after-sales service supply chain. In the second phase, the designed supply chain resilience framework was tested through a semi-structured interview method. Based on the results of the importance from the questionnaire, we categorized the enablers and vulnerabilities in the supply chain resilience framework (see Figure 5). In addition, through interviews that tested the indicators of measurement, we identified indicators that were not applicable to measure the enablers and vulnerabilities and refined them so that the supply chain resilience framework could be better applied in practice.

The improved version of the supply chain resilience framework obtained after testing can help professionals to assess the resilience of the after-sales service supply chain in the medical equipment industry. In this paper, four sub-questions were designed to help the researchers to complete the research. At the end of the research, all four sub-questions were answered. The medical equipment after-sales service supply chain is characterized by unpredictable demand and a high level of customer satisfaction. The conceptual framework consists of enablers and vulnerabilities, and the objectives set for the medical equipment after-sales service supply chain are achieved by increasing the enablers and decreasing the vulnerabilities in the supply chain to improve the supply chain resilience. A total of 11 drivers, 5 vulnerabilities, and 2 targets were identified in the supply chain resilience framework. A total of 43 indicators were obtained to measure the enablers and vulnerabilities through operationalization. We find that the question about the resilience framework and the measurement indicators has been answered only tentatively. This is because the results of the validation of the framework done so far were only obtained through semi-structured interviews. This may not be fully consistent with the results obtained through practical application testing, and therefore this resilience framework is best further improved through practical application. Therefore, there are limitations to the research in this paper that can be further improved in the future.

By analysing the limitations of this thesis, there are some recommendations for future research that will be presented next. First of all, the supply chain resilience framework designed in the paper has not been applied in practice yet. The resilience framework is currently only tested based on the experience of professionals. Therefore, the supply chain resilience framework can be used in practice to enhance supply chain resilience in the future. For example, ask professionals (decision-makers) in real supply chains to use these indicators to measure enablers and vulnerabilities, and then check if these indicators are really helpful to conduct to help measure enablers and vulnerabilities. Indicators that are not applicable in reality should be improved in time. In addition, the use of a designed resilience framework can help professionals identify which enablers need to be strengthened and which vulnerabilities need to be reduced in impact. Finally, the designed supply chain resilience framework can be verified by the extent to which the resilience is strengthened or whether the objectives are achieved.

Secondly, the testing part of this paper has some drawbacks due to time constraints. In this research, in order to save interview time, the interviews about the measurement indicators were conducted on the basis of a questionnaire, and in the second part, only the enablers and vulnerabilities that were considered to be very important were asked. Therefore, in this paper, it is not clear why the participants did not consider some of these enablers and vulnerabilities very important. Future research could explore further the reasons why those enablers and vulnerabilities were selected as unimportant.

In addition, the current methodology used to study the importance of enablers and vulnerabilities in the supply chain resilience framework is too simple. The results obtained about the importance of enablers and vulnerabilities are not very precise. For this, in future research, it is recommended to use a multi-criteria decision-making approach to investigate the importance ranking of enablers and vulnerabilities. The ranking of importance can help professionals to apply the resilience framework more effectively. This is because, with limited resources, professionals can choose to consider only the enablers and vulnerabilities that are most important to the supply chain. This can lead to optimal results by adapting the smallest inputs.

Finally, the relationship between the enablers and vulnerabilities in the framework also is stuck in literature studies and analysis of interview results. A correct and clear relationship can help users of the resilience framework to better understand the framework and avoid situations where the applicability is reduced by confusing the driving forces. Therefore, it is recommended that future in-depth studies on the relationship between push forces and vulnerability could be conducted, for example, using simulation methods.

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Appendix A- The original interview question

Introduction for the interview

This research is used to help the supply chain managers in the medical equipment industry to enhance the supply chain resilience by using a resilience framework to diagnose the supply chain.

What is supply chain resilience (SCR)?

Supply chain resilience means the ability that can restore a supply chain to its original state after an interruption or move to a new, more satisfactory state.

Statement:

- This interview will take around 30 mins.
- The interview of the resilience framework (see figure1) will be divided into two parts. First part is about the importance of enablers and vulnerabilities for the supply chain resilience. The Second part is about the indicators of enablers and vulnerabilities for the supply chain resilience.
- If you have any question during the interviewing, please interrupt and ask questions.

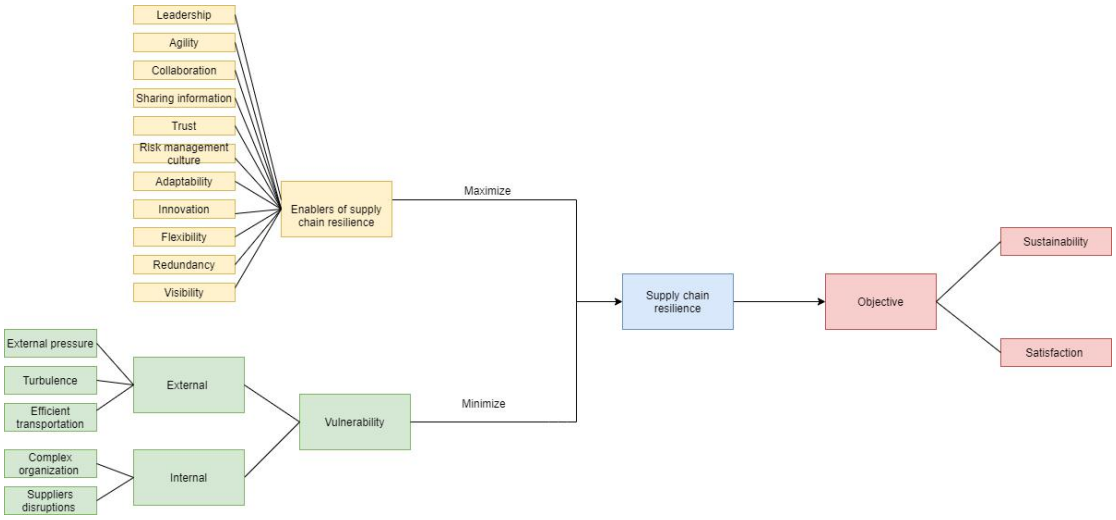

Figure 1 Supply chain resilience framework

Part 1 Importance

I have introduced the supply chain resilience before, have you understood it? Is your company adopting any SCR strategy? Could you elaborate on this? If so, can you tell me one strategy about the supply chain resilience in the company?

In this part, you need to give a choice of importance to each of the enablers. Category A the indicates that this enabler is the most important for the supply chain resilience. Category B is the important, and category C is the least important.

Enablers

1. Leadership

Leadership is always an important part of business management. Leadership can motivate a group of people to act toward achieving a common goal. Do you think that leadership is an important enabler in enhancing supply chain resilience?

2. Agility

Agility is viewed as the ability to reconfigure quickly when faced with unpredictable changes. Agility in the supply chain emphasizes rapid response and is used to help the supply chain recover quickly. Have you ever used agility? If so, can you tell us about your perception of the importance of agility to supply chain resilience?

3. Collaboration

Collaboration is the ability to joint efforts and work effectively within an organization or with other supply chain entities for mutual benefit. Do you think collaboration can be useful to enhance supply chain resilience? If so, can you give me an example that collaboration helped you enhance supply chain resilience?

4. Sharing information

Information sharing is a vital aspect of coordination amongst parties in a supply chain. Can you tell me about the sharing information that you have ever experience? How do you think sharing information can be helpful in enhancing the resilience of the supply chain?

5. Trust

How do you think about the trust relationship between supply chain parties? Do you trust other supply chain members? Do you think trust is an important enabler for enhancing the resilience of the supply chain?

6. Risk management culture

Can you tell me about your risk management culture in your company? Do you think that a risk management culture can help leaders to enhance supply chain resilience? And finally, talk about the importance of this enabler.

7. Adaptability

Adaptability is the ability to modify operations in response to challenges or opportunities. Can you tell us what you understand by adaptability or give us an example of an experience you have had with adaptability? And finally, tell us about the importance of this enabler.

8. Innovation

Can you tell us about the effect of innovations on the supply chain resilience? Do you think innovation is an important enabler for enhancing supply chain resilience?

9. Flexibility

Flexibility is viewed as an intrinsic characteristic that enables a system to adjust to change within pre-established settings。 Can you tell me an example about using flexibility to enhance supply chain resilience when you work? And talk about your understanding of how flexibility can enhance supply chain resilience. Finally, talk about the importance of this enabler.

10. Redundancy

Redundancy in the supply chain refers to keeping more inventory or production capacity in the supply chain than the normally required. However, redundancy violate the objectives of creating hyperefficient enterprises. For achieving the goal of redundancy, a company must pay for the redundant stock, capacity, and workers; moreover, such excesses are likely to lead to sloppy operations, reduced quality, and significant cost increases. How do you think about this? Do you still think the redundancy is important for supply chain resilience?

11. Visibility

Visibility means the knowledge of the status of operating assets and the environment. The ability to transparently see through all supply chain links to reduce the information asymmetry, quickly identify needs and disruptions and be able to implement changes in an effective manner. Can you give an example about using the visibility application in your work? From the example, do you know more about the importance of visibility to enhance supply chain resilience? If so, please talk about the importance of the enabler.

12. Is there any other enabler not mentioned above but is also very important to enhance the supply chain resilience?

Vulnerabilities

13. ***Supplier disruptions***

Have you ever experienced the situation that the supply chain was affected by the supplier disruption? Are there many of these situations? Do you think supply chain disruptions can be a important vulnerability?

14. Organizational Complexity

Do you think your organization structure is complex? If so, do think the complex organizational structure can influence the supply chain resilience? Does that vulnerability heavily impact supply chain resilience?

15. External pressures

Have you ever experienced the external pressures include the competitive innovation, political/regulatory change, and price pressures? How often do you experience them? Do you think external pressures could affect supply chain resilience?

16. Transportation efficiency

Are there any situations where supply chain resilience is affected by transportation efficiency problems? If so, do you think transportation efficiency can be an important vulnerability for enhancing supply chain resilience?

17. Turbulence

Turbulence includes natural disasters, unpredictability of demand, fluctuations in currencies, and pandemic. Have you ever experienced any turbulence? How does disturbance affect supply chain resilience? Do you think the turbulence is an importance for the supply chain resilience?

18. ***Is there any other vulnerability snot mentioned above but also can have a negative influence on the supply chain resilience?***

Part 2 Indicators

The interview questions in this part are about indicators. These indicators can be used to help users better measure enablers and vulnerabilities in the supply chain. Table I shows the indicators for enablers. Table II shows the indicators of vulnerabilities.

Table 1 The indicators for the enablers

Enablers	**Indicators**
Leadership	The degree of emphasis on supply chain resilience The power to implement the supply chain resilience The degree of knowing the resilience influences the ability of leaders to make resilience decisions.
Agility	Time to respond Time to access relevant data Time to detect threats
Collaboration	The degree of collaborative forecasting Efficiency of communication Supplier delivery efficiency
Sharing information	The accuracy of prediction Inventory management efficiency The probability of uncertainty
Trust	The length of time that the relationship lasts is an indicator of trusting behavior between the buyer or the seller. Confidential information sharing Additional protection that the assumption by one party of an acknowledged or accepted duty to protect the rights and interests of the other party.
Risk management culture	Incentive and Punishment of risk management culture Risk management knowledge Risk management culture training
Adaptability	The speed of re-routing the requirements Learning from experience
Innovation	Innovation in management Innovation in services
Flexibility	The spare part-supplier rate The rate of deliver on time Customer Evaluation Technological flexibility
Redundancy	Stock level Warehouses and facilities spread
Visibility	Information technology Information exchange Forecast error The ease of acquiring the information

Enablers

1. Leadership

（1） Do you think your current team pays attention to supply chain resilience? If so, do you feel that emphasis on supply chain resilience helps a lot to improve supply chain resilience? Do you think this indicator can reflect the leadership of supply chain resilience?

（2） Do you think the degree of power in implementing supply chain resilience can be used to measure leadership?

（3） Do you think the degree of the leaders knowing about the supply chain resilience can be used to measure the leadership?

2. Agility

（4） During the covid-19 pandemic, commodity flow, cash flow, logistics and information flow were affected by the pandemic. Would you define your company agile? From 1 to 5? Which measure you took to recover from an unexpected situation? And how long did the flow take to recover? Moreover，do you think time to respond can be used to measure agility in the supply chain?

（5） Can you access relevant data quickly in order to decide how to act? Do you think the quick access the data of the company has a positive effect on the recovery of the supply chain? If so, do you think time to access data can be used as an indicator for the agility？

（6） Do you agree with that time to detect threats can be regard as a indicator for measuring agility? And why?

3. Collaboration

（7） Have you ever experienced collaborative forecasting? If so, how often do you use the collaborative forecasting method? Do you think the frequency of collaborative forecasting can be used to measure supply chain collaboration?

（8） Do you think the communication is important for the collaboration? Do you think the efficiency of collaborative communication can measure the supply chain collaboration?

（9） How is the delivery efficiency of supplier you cooperate with? Do you think the delivery efficiency of supplier can be used to measure the supply chain collaboration?

4. Sharing information

（10）How do you think about the efficiency of sharing information for the supply chain in your company? Do you think the accuracy of the prediction can be used to measure the sharing information?

（11）Is it meaningful to use the inventory management efficiency measure the efficiency of sharing information?

（12）When the information is lacking, how will the supply chain be affected? Do you think it is possible to use the probability of uncertainty to measure sharing information for the supply chain resilience?

5. Trust

（13）Normally, how long does the relationship last between the buyer or the seller? Do you think the length of time that the relationship lasts can be an indicator of trust?

（14）How do you think trust in the medical equipment supply chain? Do you want to share confidential information with them?

（15）When you trust others in the supply chain, do you give an acknowledged or accepted duty to protect the rights and interests of the other party? If so, do you think the additional protection can be the indicator of the trust?

6. Risk management culture

（16）Is there any incentive and punishment about the risk management culture in your company? If so, do you think this indicator can measure risk management culture?

（17）Do you think the managers of the supply chain know enough risk management knowledge? Is this useful to measure this enabler by the level of relevant knowledge?

（18）Is there any training about risk management in your company? If so, have you ever joined this training? Do you think this training is useful for you to enhance the supply chain?

7. Adaptability

（19）During the covid-19 pandemic period, does the supply chain department modify operations in response to challenges? Does the supply chain re-route the requirements fast? Do you think it could be used as an indicator of the speed of re-route the requirements?

（20）Do you think the learning from experience can help the supply chain recovery fast? Do you agree that using the indicator to measure adaptability?

8. ***Innovation***

（21）Have you ever done these innovations for the supply chain? Do you think innovation in management can be indicator of innovation？

（22）Is there any innovation in service in your supply chain? Do you think the innovation in service can be regard as indicator of the innovation in the supply chain?

9. Flexibility

（23）What do you think of the flexibility of suppliers? Can this indicator help you learn more about the flexibility in the supply chain resilience?

（24）Would you like to use the indicator- *rate of deliver on time*-to measure the supply chain flexibility?

（25）Could customer evaluations measure the flexibility of services?

（26）Recently, the speed of technological upgrading is gradually high. Flexibility in technology can be used to accommodate change. Do you think flexibility in technology can be used as an indicator to measure the supply chain flexibility？

10. Redundancy

（27）Is there a safety-stock in the supply chain? If so, do you think stock-level can be used as an indicator of measuring redundancy in the supply chain?

（28）For your company, how is the warehouse and facilities distributed in supply chain? Do the warehouses and facilities spread throughout the world? Do you want to use the of spread

warehouses and facilities to measure redundancy?

11. Visibility

（29）Visibility means the knowledge of the status of operating assets and the environment. Do you think the information exchange and the information technology can be used to measure the visibility?

（30）Do you think the visibility can improve the accuracy of predictions? If so, do you think that forecast error could be used as a measure of visibility?

（31）How easy or difficult it is to acquire a given piece of information in your company? If it is easy, does it show a better visibility for the supply chain?

Table 2 The indicators of vulnerabilities

Vulnerabilities	**Indicators**
Supplier disruptions	Frequency of occurrence per type of event. The level of the supplier reliability. Number of suppliers per type of goods. The amount of the spare parts stock.
Organizational Complexity	The number of the hierarchical layer of the organizational chart. I The number of the decision makers involved in a project. The number of the processes and rules
External pressures	Product Sales Volume Monitoring the political events The fluctuation of price
Transportation efficiency	The time of customs inspection The number of the delayed delivery of orders
Turbulence	None

Vulnerabilities

12. ***Supplier disruptions***

（32）Do you think the frequency of occurrence per type of event can help you solve the vulnerability supplier disruptions? And how about the supplier reliability?

（33）If there is only one supplier for one spart part, the supplier disruption is more likely to happen. Do you think that the number of suppliers for each good can be used to measure supplier disruptions?

13. Complex organization structure

（34）How many hierarchical layers of the organizational chart? Do you think your current organizational structure is complex? How many hierarchical layers in the organizational chart will be recognized complex？

（35）How many people will be involved in a decision-making process? Do you think use the number of decision makers is to measure the organizational complexity appropriate?

（36）Do you think the processes and rules in your company will influence the efficiency of your work? Does it need to be simplified? Do you think the existing redundant processes and rules can measure the complexity of organizational structures？

14. External pressures

（37）Do you think the lower product sales volume than the competitors will show the that the company is facing external pressure?

（38）How do you think about the influence of the new political/regulatory on supply chain resilience in the medical equipment industry? Do you think the external pressure can be measured by monitoring the political events?

（39）Is it meaningful to measure external pressure by monitoring the fluctuation of price?

15. Efficient transportation

（40）Does the customs inspection usually take a long time? Does the time of customs inspection influence the transportation efficiency?

（41）Can you know about the efficiency of the transportation by accounting the number of the delayed delivery of orders which influenced by the transportation? If not, how to measure the efficiency of the transportation?

16. Turbulence

（42）Are there indicators that you think can measure turbulence? Can you tell us about such indicators?

Appendix B- The improved interview questions

This study is used to help supply chain managers in the medical equipment industry improve the resilience of their supply chains by using a resilience framework to diagnose their supply chains.
What is supply chain resilience **(SCR)?**
Supply chain resilience, also known as supply chain resilience, is the ability to maintain continuous supply chain operation and recover the supply chain to its original state, or to a new, more stable state, in the event of partial supply chain failure.

Statement
- This questionnaire is used to investigate the importance of enablers and vulnerabilities in the supply chain resilience framework (see below for the framework).
- The questionnaire divides the level of importance into three levels. The first level is very important, which refers to the element that you think is very important for supply chain resilience. The second level is important, where you may feel that this element is important, but are not sure about choosing this option. The third level is not important, where you think, this element does not contribute to supply chain resilience and is not important.
- In the process of answering, if you have any questions, you can contact me by email. My email address is Y.Bing@student.tudelft.nl.

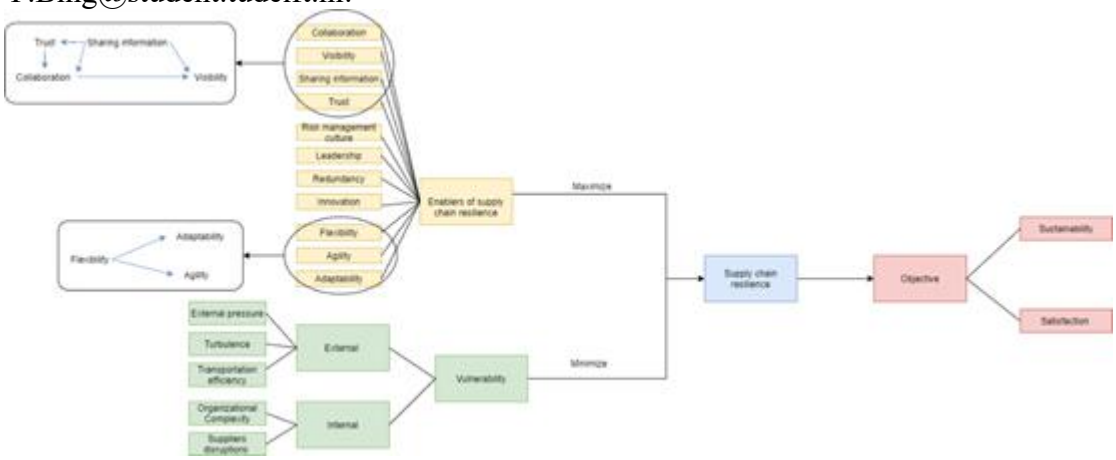

Figure 1 Supply chain resilience framework

1. Please fill in your nickname *

_____

2. 【**Leadership**】 Leadership has always been an integral part of business management. Leadership can motivate employees to work towards a common goal. In your case, do you think leadership is an important enabler of supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

3. 【**Agility**】Agility is defined as the ability to quickly rearrange in the face of unpredictable change. Supply chain agility emphasizes the ability to respond quickly. Agility can help the supply

chain return to a state of balance more quickly. Please make your choice on how important agility is to supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

4. 【**Collaboration**】Collaboration refers to the ability to work together and effectively within an organization or with other supply chain entities to achieve mutual benefits. You are invited to make a choice about the importance of collaboration. [Single-choice question] *

○Very important

○Important

○Not important

5. 【**Sharing information**】Sharing information is considered to be an important aspect of coordinating all parties in the supply chain. Are there examples of shared information in your work? Please make your choice about the importance of sharing information. [Single-choice question] *

○Very important

○Important

○Not important

6. 【**Trust**】Trusting suppliers is important for purchasers to make flexible decisions. The role that trusts plays in a partnership comes to the fore when the partnership is in trouble. Trust works both ways in ensuring the integrity of any supply chain. So, do you think trust is important in enhancing the resilience of the supply chain? [Single-choice question] *

○Very important

○Important

○Not important

7. 【**Risk management culture**】Do you think the risk management culture that exists in your company is important for enhancing supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

8. 【**Adaptability**】Adaptability refers to the ability to adapt to external changes. Specifically, it refers to the ability of the supply chain to adapt to structural changes in the market and shifts in corporate strategy. Do you think this enabler is important to enhance the resilience of the supply chain? [Single-choice question] *

○Very important

○Important

○Not important

9. 【**Innovation**】The innovation factor here mainly refers to the innovation of supply chain systems and processes. Do you think innovation is an important enabler for enhancing supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

10. 【**Flexibility**】Flexibility is seen as an inherent characteristic that allows the system to adapt to change within a pre-established setup. Can you judge the importance of this enabler for supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

11. 【**Redundancy**】Redundancy in the supply chain refers to maintaining more inventory or production capacity in the supply chain than is normally required. However, redundancy is considered to be contrary to the goal of creating an efficient business. In order to achieve the goal of redundancy, companies must pay for redundant inventory, capacity and workers; furthermore, this overuse can lead to sloppy operations, reduced quality and significantly higher costs. How would you judge the importance of redundancy to supply chain resilience in this regard? [Single-choice question] *

○Very important

○Important

○Not important

12. 【**Visibility**】Visibility is the understanding of the state of operational assets and environment, including visibility into business processes, visibility into KPI performance, etc. Visibility enables members within the supply chain to see all supply chain links, reduce information asymmetry, quickly identify needs and disruptions, and enable changes to be implemented in an effective manner. Do you think visibility is important for enhancing supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

13. In addition to the enablers in the framework, can you give examples of other enablers used to enhance supply chain resilience?

_____

14. 【**Supplier disruptions**】Have you ever experienced a supply chain disruption due to a supplier disruption? Do you consider supplier disruptions to be a significant vulnerability for supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

15. 【**Organizational Complexity**】Complex organizational structures are considered to have some impact on the supply chain. Do you think that organizational complexity is important for supply chain resilience? [Single-choice question]
[Single-choice question] *

○Very important

○Important

○Not important

16. 【**External pressures**】External pressure refers to competition, price pressure, and changes in policies and regulations. Do you think external pressure is a significant vulnerability for supply chain resilience? [Single-choice question] *

○Very important

○Important

○Not important

17. 【**Transportation efficiency**】Transportation inefficiencies can have an impact on the proper functioning of the entire supply chain. Please evaluate the importance of transportation efficiency to supply chain resilience. [Single-choice question] *

○Very important

○Important

○Not important

18. 【**Turbulence**】Turbulence refers to natural disasters (earthquakes, hurricanes, etc.), unpredictability of demand, etc. Do you think this vulnerability is important for the resilience of the supply chain? [Single-choice question] *

○Very important

○Important

○Not important

19. Are there other vulnerabilities that are not mentioned but can also negatively impact supply chain resilience?

_____

Part 2-interview questions

The interview questions in this part are about indicators. These indicators can be used to help users better measure enablers and vulnerabilities in the supply chain. Table I shows the indicators for enablers. Table II shows the indicators of vulnerabilities.

Table 1 The indicators for the enablers

Enablers	**Indicators**
Leadership	The number of resilience strategies or decisions The magnitude of supply chain resilience power The degree of leadership understanding of supply chain resilience
Agility	Time to respond Time to access relevant data Time to detect threats
Collaboration	Frequency of collaborative forecasting Efficiency of communication Supplier delivery efficiency
Sharing information	The accuracy of prediction Inventory management efficiency The probability of uncertainty
Trust	The length of time that the relationship lasts between the buyer or the seller Confidential information sharing Existence of mutually beneficial cooperation terms
Risk management culture	Incentive and Punishment of risk management culture Risk management knowledge Risk management culture training
Adaptability	The speed of re-routing the requirements Learning from experience
Innovation	Innovation in management Innovation in services
Flexibility	The spare part-supplier rate The rate of deliver on time Customer Evaluation Technological flexibility
Redundancy	Stock level Warehouses and facilities spread
Visibility	Information technology Information exchange Forecast error The ease of acquiring the information

Enablers

1. Leadership

- Do you think your current organization values supply chain resilience? If yes, do you think valuing supply chain resilience helps a lot to improve supply chain resilience? Do you think this indicator is reflective of supply chain resilience leadership?
- Do you think the level of power to implement supply chain resilience can be used to measure leadership?
- Do you think it is appropriate to measure leadership by how well leaders know about supply chain

resilience?

2. Agility

- During the covid-19 pandemic, commodity flow, cash flow, logistics, and information flow were all affected by the epidemic. Would you define your company's agility? From 1 to 5? What steps did you take to restore your supply chain? How long did it take for the flows to recover? In addition, do you think response time can be used to measure agility in the supply chain?

- Do you have quick access to relevant data to decide how to act? Do you believe that quick access to company data has a positive impact on supply chain recovery? If so, do you think the time it takes to put data on hold can be used to measure agility?

- Do you believe that the time to detect threats is a good indicator of agility? Why?

3. Collaboration

- Is there any experience of collaborative forecasting in the team? If so, do you often take a collaborative forecasting approach? Do you think the frequency of collaborative forecasting can be used to measure supply chain collaboration?

- Do you think communication is important for collaboration? Can efficiency of collaborative communication be used as an indicator to measure supply chain collaboration?

- How efficient are the suppliers you work with in terms of delivery? Do you think the indicator of supplier efficiency can be used to measure the collaboration in the supply chain?

4. Sharing information

- Can you evaluate the efficiency of information sharing in your current work? Do you think the accuracy of predictions gives an idea of the efficiency of information efficacy?

- Do you think it would be meaningful to understand information sharing by measuring the efficiency of inventory management?

- When information is missing, how do you think the supply chain is affected? Do you think it is possible to use uncertainty probabilities to measure shared information about the resilience of the supply chain?

5. Trust

- What is the longest relationship lasting that you know of with a supplier? Do you think the time length of the relationship can be used as an indicator of trust?

- How do you feel about trusting the medical equipment supply chain? Do you want to share confidential information with them?

- When you trust others in your supply chain, do you give recognition or acceptance of responsibility to protect the rights and interests of the other party? If so, do you think additional protection can be a measure of trust?

6. Risk management culture

- Are there any incentives and punishment regarding risk management culture in the company? If so, do you think this indicator can be used to measure the risk management culture?

- Do you think that supply chain managers have sufficient knowledge of risk management? If yes, do you think it is appropriate to measure this enabler by the level of relevant knowledge?

- Does your company have any training on risk management? If so, have you attended such training? Do you think this training would be useful for you to improve your supply chain?

7. Adaptability

- During the covid-19 pandemic, did the supply chain department adapt the supply chain due to the challenges? Was the organization able to re-route the requirements quickly? Do you think it is possible to use the speed of re-route the requirements as an indicator?

- Do you think the learning from experience can help the supply chain recovery fast? Can learning from experience be used as a measure of adaptability?

8. ***Innovation***

- Have you been involved in innovation in supply chain management? Do you think management innovation can be used as an indicator for measurement?

- Has the company ever created innovations in the services it provides to its customers? Do you think this innovation in service can be used to measure innovation in the supply chain?

9. Flexibility

- How do you view the flexibility of suppliers? Does judging the flexibility of suppliers help you measure the flexibility of your supply chain?

- Can on-time delivery rates help you measure supply chain flexibility?

- Can customer evaluations be used to measure the flexibility of services?

- Recently, the pace of technology upgrades is gradually accelerating. Technological flexibility can be used to adapt to change. Do you think technological flexibility can be used as a measure of supply chain flexibility?

10. Redundancy

- Is there a safety-stock in the supply chain? If so, do you think stock levels can be used as an indicator of redundancy in the supply chain?

- For your company, how are the warehouses and facilities distributed in the supply chain? Are the warehouses and facilities distributed around the world? Is it possible to use the spread of warehouses and facilities to measure redundancy?

11. Visibility

- Visibility means the knowledge of the status of operating assets and the environment. Do you think the information exchange and the information technology can be used to measure the visibility?

- Do you think that visibility can improve the accuracy of prediction? If so, do you think that forecast error can be used to measure visibility?

- In your company, is it easy or difficult to obtain a particular piece of information? If it is easy, does it indicate a high visibility of the supply chain?

Table 2 The indicators of vulnerabilities

Vulnerabilities	Indicators
Supplier disruptions	Frequency of occurrence per type of event. The level of the supplier reliability. Number of suppliers per type of goods.
Organizational Complexity	The number of the hierarchical layer of the organizational chart. I The number of the decision makers involved in a project. The number of the processes and rules
External pressures	Product Sales Volume Monitoring the political events The fluctuation of price
Transportation efficiency	The time of customs inspection The number of the delayed delivery of orders
Turbulence	None

Vulnerabilities

12. ***Supplier disruptions***

- Do you think the frequency of each type of event can help you deal with supplier disruptions? In addition, can supplier reliability help you measure supplier disruptions?

- If there is only one supplier for a commodity, it will be vulnerable to supply disruptions. Do you think that the number of suppliers for each good can be used to measure supplier disruptions?

13. Complex organization structure

- Do you know how many levels there are in the organization chart of your company? Do you think your current organizational structure is complex? How many hierarchical levels do you think would be considered complex in a typical organization chart?

- How many people are typically involved when making a decision? Do you think it is appropriate to use the number of decision makers to measure the complexity of an organization?

- Do you think your company's processes and rules affect your productivity? Does it need to be simplified? Do you think it is reasonable to use existing redundant processes and rules to measure the complexity of the organizational structure?

14. External pressures

- Can lower product sales compared to competitors indicate that the company is facing competitive pressure?

- How do you see the impact of new politics/regulations on supply chain resilience in the medical device industry? Do you think external pressures can be measured by monitoring political events?

- Does it make sense to measure external pressures by monitoring price fluctuations?

15. Efficient transportation

- Does the customs inspection usually take a long time? Does the time of customs inspection influence the transportation efficiency?

- Can you get an idea of the efficiency of shipping by calculating the number of delayed deliveries of

orders affected by shipping? If not, how can you measure the efficiency of transportation?

16. Turbulence

- Do you think there are indicators that can measure turbulence? Can you tell us about such indicators?

Appendix C- The data of questionnaire

Appendix C1- Data of questionnaire of enablers

Enablers	Options	Number	Percentage
Collaboration	Very important	10	100%
	Important	0	0
	Unimportant	0	0
Visibility	Very important	7	70%
	Important	2	20%
	Unimportant	1	10%
Sharing information	Very important	10	100%
	Important	0	0
	Unimportant	0	0
Trust	Very important	9	90%
	Important	1	10%
	Unimportant	0	0
Risk management culture	Very important	7	70%
	Important	3	30%
	Unimportant	0	0
Leadership	Very important	6	60%
	Important	4	40%
	Unimportant	0	0
Redundancy	Very important	6	60%
	Important	1	10%
	Unimportant	3	30%
Innovation	Very important	7	70%
	Important	3	30%
	Unimportant	0	0
Flexibility	Very important	7	70%
	Important	3	30%
	Unimportant	0	0
Agility	Very important	10	100%
	Important	0	0
	Unimportant	0	0
Adaptability	Very important	8	80%
	Important	2	20%
	Unimportant	0	0

Appendix C2- The data of questionnaire of vulnerabilities

Vulnerability	**Options**	**Number**	**Percentage**
Supplier disruptions	Very important	5	50%
	Important	3	30%
	Unimportant	2	20%
Organizational Complexity	Very important	5	50%
	Important	4	40%
	Unimportant	1	10%
External pressures	Very important	5	50%
	Important	3	30%
	Unimportant	2	20%
Transportation efficiency	Very important	7	70%
	Important	3	30%
	Unimportant	0	0
Turbulence	Very important	2	20%
	Important	6	60%
	Unimportant	2	20%

Appendix D- The transcribed recordings

Participant A1

Q: Why do you think leadership is very important? What would you use to evaluate leadership for supply chain resilience? And would you like to use these indicators that I provided to access leadership?

A: I would like to observe leadership from both a personal and an organizational perspective. Personal leadership is demonstrated when I meet a difficult situation that cannot be solved by the previous standard process or routine operation, then I will be more active and try to solve the problem in time by trying to think of various ways, or by asking to discuss with others the pros and cons of my proposed solution and discussing its feasibility. This aspect also shows that leadership is very relevant to another factor of collaboration. Because leadership is the ability to have a very smooth cooperation with other departments when problems are encountered, so that problems can be solved smoothly and in a timely manner.

From the organizational side, leadership requires a strong core. When the members below or in the department encounter some difficulties, the manager can find a way to coordinate the higher-level resources to solve the problem.

Q: Do you evaluate agility in terms of response time, time to access relevant data and time to detect the presence of a threat?

A: I think agility can be seen in terms of prediction. For example, if you have an event that affects the resilience of the supply chain, but you need to recover to an original state or a new stable state, the time from when the supply chain is affected to when you take action to recover the supply chain is what you call reaction time. If I have a predictive, another prediction of what is going to happen, then I can reduce the response time, that's why I said I will observe the agility from the predictive ability.

For example, there is an unexpected situation on the supplier's side, and suddenly the delivery date needs to be extended, in this kind of situation, the company is in a relatively passive state. If the supply chain is to be restored to a balanced state, or a normal state of supply, it will take some time to take some actions, such as how to lay out the goods or rush materials, and then to shorten the impact of the supplier's unexpected situation, until the next balanced state, leaving a batch of goods to the middle of the state, so the response is to respond to this change. In this regard, the more important point is that, in response to this change, the person in charge needs to think of various ways, such as coordinating other available resources, or doing some negotiations to try to get the supplier to solve the problem as soon as possible. But I think the more important thing here is a predictive, for risk assessment. Because if the supplier changes a lot, does it mean that something is going to happen? For example, the supplier must be the first to inform us of the situation, we can work together with the supplier to find a solution. Prediction is to have a certain amount of preparation for the risk, the risk will be placed in the early stage. If there is a certain forecast upfront, the supply chain will have a certain preparation, which is a is a proactive behavior. Here we can say that we tend to plan our inventory by taking into account the historical consumption data for spare parts in the after-sales service supply chain. If the market itself has a basic growth, the market demand for spare parts is constantly rising, only according to the historical consumption data to make plans, it will always be in a lagging state. So, if there are various resilient factors that can be considered in advance, for example, when planning, we can consider the basic growth on the consumption of a proportion of the impact of such a preliminary intervention, can solve the subsequent unpredictable changes.

Q: Do you think the indicators I've given will help you evaluate the collaborative of the supply chain?

A: First of all, I think the supplier delivery delay rate cannot be used to measure the supply chain collaboration, because not all delays are caused by collaboration. And the supplier's external collaboration,

this is only part of the reason, for example, and the supplier because there is no timely communication, resulting in information asymmetry, and then led to the delay in delivery, which must be investigated what the reason, this is certainly the impact of collaboration.

In addition, I think the collaboration within the supply chain is reflected in whether the thing can be driven to go on. Because whether it's a process or an organization, it's not simply one person doing one thing, Siemens' process is very subdivided. For example, if I want to provide a spare part, my process is that I need to return it for repair and send it back after it is repaired, so there must be a lot of departments involved in this part, and as long as one of them does not cooperate, or there is a little situation in the middle, we will immediately have a response within the supply chain. Then there is another example of my customs clearance action, often according to the requirements of different countries' customs policies, and then or it's a process above the restrictions, want to smooth customs clearance, I certainly need to collaborate with various departments involved in the process, to discuss with them how the whole process to proceed.

Q: I'm curious why you think the risk management culture is important for supply chain resilience? Because not everyone thinks this enabler is important for supply chain resilience.

A: Regarding this risk management, including our U.S. companies, there is a risk medication group or team. When it comes to force majeure or there are some risky situations, for example, like hurricanes in the United States, the team will make a timely forecast. In addition, there are some things that the supplier may not have thought of on his side, so the company has to have a way to remind the supplier. For example, because many of the new crown Spain Italy side is also closed city, this time the company will communicate with the supplier, ask if there are sub suppliers are from these places. Our sourcing will have an advance notice, ask him if you have the following sub-suppliers will cause you sub component supply problems, if you have now found that there is this problem, you have to tell me, some suppliers may not be aware of himself, then with our such a trigger, which is also for the risk of a control in advance to maintain. If we hear what kind of problems this supplier has, this market may be in a similar form, another supplier may not have placed an order, or he is not aware of the problems in this market, if the procurement or have a pre-control word, can share the information in advance to him, we said we now found what problems in the market, for you this is not a problem. If he has an advance notice, he will win a lot of time for us to solve the problem, so risk control is certainly very important, but the difficulty of risk control is that I often do not realize that there is such a risk, this is more difficult.

Q: Do you think the indicators I have given you can help you evaluate the sharing information in the supply chain?

A: For forecasting, information is a very important factor. When building a supply chain forecasting model, you need to use a lot of information, such as how much money I want to invest and what you expect a return to be. First of all, the external information sharing, the performance between the company and the supplier is good or bad, it needs to be reflected by KPI or score card, which is a feedback of information. Through this kind of balanced score card company side can detect or control suppliers every month, and then let each other have an overview, to know this performance is good or bad, so this can be sharing information with the supplier. In addition, information sharing about risks, for example, the supplier found some risks in the market supply, communicate with the company, this is also a kind of information sharing, to help us solve the problem quickly so that we can reduce the risk. For the supply chain in the company, if we find that there may be a certain amount of increase in production demand in the market, and there is a possibility of such a large increase, we will place orders in a timely manner, or propose such an incremental demand with suppliers, which is considered an external information sharing.

The internal information sharing is more about the supply chain allocation. For example, if a customer has an order, our customer will be the first to give feedback to the deliver department, for instance, he will adjust its inventory. Because a certain time may cause some traffic pressure to rise, so need to stock in advance, this kind of information also need to communicate with the procurement side in advance. Then to coordinate how

to optimize the inventory, how to supply. So that internal information is also very important, because this case procurement needs to communicate with the upper level of suppliers in advance, not to the final node, and then communicate with the warehouse and logistics colleagues, temporary delivery, which will affect the efficiency of the entire supply chain. The warehouse has its own plan, if you want to adjust the inventory, suddenly need to replenish more goods in the warehouse or procurement suddenly adjust the inventory, but did not share this information to the warehouse in advance, will face the warehouse does not have enough space to store accessories. Such an advance communication will involve a wide range of information, and will involve the important departments, all related departments. The important thing is to share the right information to the right people. Since there are a lot of internal company emails every day (meaning CC), the information needs to be targeted to the right people.

Q: How do you think about agility, adaptability and flexibility? How do you differentiate these three enablers?

A: For adaptability one can give an example of an uncertain situation concerning the next level of the market. For example, electronic parts are now in a very scarce situation, so for this situation, my current standard process may not be able to adapt to the previous model of doing planning. Under normal circumstances, purchasing can give orders to suppliers according to lead time, and suppliers will ship regularly, but when I want to rush the goods in the middle, suppliers can expedite the goods. But now these markets have not allowed me to have this kind of a posture on the A side, this time the supplier will require the company to provide the forecast demand, and this forecast demand is necessary to do confirm, or directly to me to place a purchase order, this is some of the current daily standardized operation, in response to this situation, I should not change our current A standard model, or a new way to adapt to the outside world, because the external changes caused by changes to the supply chain has an impact, adjust the supply chain to adapt to changes is said to adapt.

Agility is the ability to seek resources to solve the problem quickly after the problem arises. One is for cases with special characteristics, one is for that is the overall structure of my whole process of a change. Flexibility means that I have a predetermined plan and a definite lead time, but I may adjust my plan at any time. As a supplier, you have to adjust to my needs. Our then if I speak to the customer, the customer will sometimes say I suddenly I need a lot of replenishment, for us is actually also a certain degree of consideration. Another way to improve flexibility is by investing money, investing more money, stocking more, which can increase flexibility, so you can use the amount of money invested to judge its flexibility. Especially for our after-sales supply, unlike the production side of the supply chain he may have a customer order demand every month, he has a forecast in advance, he can give to the supplier, but we do not have this side, because I do not know when to change it, for us on this flexibility is a little weaker, if there is no large amount of capital support.

The processes of the organizational structure need to adapt to the changes in the market, and this transformation process may have to consider the factor of flexibility. And then for agility, if it improves, then my flexibility will also improve. But for agility, I have another idea, for example, I have the ability to take action, but can I solve it, how long it will take to solve it in the end, this is a problem. My agility to improve does not mean that I said my flexibility will be achieved immediately, it is possible that the problem itself is difficult, even if I quickly take action to seek help, but in the end may still need a long time to coordinate to solve the problem, and finally solve the problem, yes, but if even the agility cannot reach the words, the first step is not out, it is certainly impossible for the back.

Q: I'm curious, why do you think innovation is very important for supply chain resilience?

A: I think innovation is going to impact supply chain resilience. There is a platform for innovation in the daily work of the company, and for us innovation is especially reflected in the improvement of processes. For example, for the transportation of medical parts is very demanding, it is important to have clear information about the logistics that can be viewed, especially when it comes to international logistics, you

have to have this kind of electronic information at all levels, which is not so easy. We will also discuss the last mile, maybe that means how to open it up in the last mile, at present, our department's supply chain is connected to the country, not the customer, how to be able to track its final customer, this is a project in progress. If we are still using the model of 10 years ago, we need to pay attention to innovation and design a more convenient model that can be adjusted anytime and anywhere, or how to optimize a platform for forecasting, which is also very important to me, and this can also improve the supply chain to a large extent.

Q: What do you think about redundancy, and is it possible to measure redundancy in the supply chain in terms of stock levels?

A: The redundancy will give the supply chain a certain amount of security. Now the supply chain market is unstable, then many people may say the only way is that you have to stock up, this action is not that the same day to do the same day the results, so need to take a certain risk, a certain amount in advance of the next year as my safety stock, which is also an early intervention, but this is going to cost a certain amount of money. This time there is a balance, for example, medical equipment company is to market customer market as the main goal, so there is no way to reduce the service performance and delivery capacity, because it directly affects the company after the customer business development. Therefore, the supply chain of medical parts needs to be shipped immediately after the customer places an order, instead of ordering after the customer has placed an order.

Participant A2

Q: What are your comments on the questionnaires you have done before?

A: First of all, in the vulnerability part you think the complexity of the organizational structure will have a negative impact on the supply chain. But I actually think the complex organization will have a positive impact on the supply chain this may be. For example, if your organizational structure is relatively single, you actually have only one line from the front end to the back end, if the organizational structure is relatively a little more complex, it will have a lot of cross lines. Once the supply chain on one line is interrupted, we can seek some help from other directions of your whole organizational structure. In this way, the relative complexity of your organization should be an advantage, not a disadvantage. Take my company as an example, I think it is relatively complex organization structure, then there will not be a single supply chain. If there is an interruption in our own supply chain line, we can also seek other help, this thing is both advantages and disadvantages, the disadvantage is that it is possible to layer upon layer of the organizational structure is more complex, it is possible to say that the information is missed or wrongly transmitted, will cause great impact, or in turn, the information transmission time is too long, cannot be conveyed in a timely manner.

Q: Your questionnaire indicates that you consider agility to be very important. Do you think response time, time to access relevant data, and time to detect threats can help you assess supply chain agility?

A: I think the time to detect the threats is not very appropriate for assessing agility. If the customer satisfaction is low, you are sure that the agility is not high, this satisfaction is not that he is satisfied with our service, but that he placed an order, we can ship within his specified time, or can be delivered to the customer's hand as soon as possible. If the fastest delivery, then the customer's satisfaction is high. There is also the ability to send out the goods ordered by the customer at one time is also an indicator, for example, the customer orders to buy 10 pieces of parts, if I can immediately provide 10 pieces to the customer, then meet this indicator, customer satisfaction will be high, if I say that I now have only 3 pieces in stock, the other 7 pieces need to wait half a month later, although this is also considered to have been sent, but the goods sent did not reach the customer ordered this quantity This will not meet the indicator I mentioned.

Q: I provided two indicators to evaluate supply chain collaboration, the first is the frequency of collaborative forecasting and the second is the efficiency of communication, do you think the two indicators are meaningful?

A: I think those two metrics are fine. Perhaps leadership could be used to assess collaboration as well, but I'm not really sure.

Q: This question is about sharing information. Do you think the metrics I've provided can be used to measure shared information in the supply chain?

A: I think sharing information and forecasting are related. So I think the accuracy of forecasting can be used to measure shared information, but I don't think inventory management can be related to sharing information.

Q: For the trust enabler, do you think these metrics can be measured, and if not, what indicators do you think can measure it?

A: I think all of the indicators you mentioned can be used to measure trust. But I think another way to consider that is the complaint rate about your supplier partners. The more complaints you have about your partners, the more you doubt them, and the less you trust your partners.

Q: The next one is adaptability. Do you think the indicators of adaptability are reasonable?

A: I think the indicators you're providing are reasonable, but I think you can also think about adaptability in terms of innovation. Because the environment is constantly changing, the more you innovate, the more you are trying to adapt to these changes. So, you can have a indicator of innovation to measure adaptability.

Q: Do you think the four indicators I provided to measure supply chain flexibility are appropriate?

A: First of all, I think the ratio of the number of suppliers to the number of parts that you're talking about is a good measure of flexibility. I also think that flexibility can be measured by the supplier's lead time, whether the supplier is within the lead time for each delivery, which is actually about the reliability of the supplier. On-time delivery rate I also think can measure flexibility, but I think this refers to whether the goods can be sent out according to the specified time. In addition, I think you can also add a shipping time efficiency, which refers to the probability of the customer receiving the goods on time. Because sometimes it is not that if you send out the goods on time, the customer can receive the goods on time, this will also be affected by the transportation. In addition, inventory flexibility can also be used to measure supply chain flexibility. Here the flexibility of inventory can be measured by the indicator of agility - whether the goods can be shipped in one single order or not. Finally, I don't really agree with service flexibility, which I think is not a good measure of supply chain flexibility.

Q: The last question is about redundancy. Do you think stock levels and also the spread of the warehouse can be used to measure your redundancy level?

A: I think redundancy can be measured by stock. The fact that your stock is higher than your daily demand level means that there is redundancy in stock. I think you can measure redundancy in terms of turnover rate, and if the turnover is high, then the redundancy is low. For example, if you have an inventory of 100 and you only use 30 of them every month, you have a turnover rate of only 30%. But I don't think the number of warehouses and the distribution means it's more redundant. I think the most relevant or painful inventory to measure.

Q: Why do you think transportation efficiency has a significant impact on supply chain resilience? Do you think these indicators can be used to measure transportation efficiency?

A： I think the impact is very big, especially in the case of the global epidemic now is very important. For example, before 19 years, our total accounting for Asia and Europe was about three days, but now, due to the force majeure of the epidemic, we have to disinfect our shipments to customs, and then we have to change planes, and due to the global epidemic, there is no direct flight, we have to change all kinds of things, and then we have to disinfect in the middle, that is very inefficient. I think the orders that are not delivered on time it is not necessarily because of transportation problems, it is also possible that the goods are not available, so the date of delivery is later. I think you can point out between the number of orders that are delayed due to shipping.

In addition, you can also measure it from the perspective of the route, if the route is optimized first, then the transportation efficiency will definitely be high. I think you can consider from the perspective of the volume of goods. Because generally the more the volume of goods, the slower the transportation. Because you have a lot of volume, he arranged into a batch, for example, you have two tons of this batch, my need to give you a reservation of two tons of warehouse, then it is possible that small pieces will be easy to stuff. Finally, there may be an indicator that belongs to the carrier's transport capacity, depending on how much capacity your carrier has, and how much this will also affect the efficiency of transport.

Participant B1

Q: Can you tell me about the background of your company? What type of business is it, and what are the related businesses?

A: Our company belongs to private enterprise. We do both medical equipment and medical consumables.

Q: Your questionnaire indicates that you consider agility to be very important. So, do you think response time, time to access relevant data, and time to detect threats can help you assess supply chain agility?

A: I agree with what you said about these indicators. In addition, I think you can also measure agility in terms of inventory. For example, if a customer makes an order, if the item is directly available in the warehouse, then it can be sent to the customer very quickly, if it is not available in the warehouse, and you have to order after placing the order, the fold is completely different, so there will be a waiting time.

Q: The next question is about collaboration. Do you think the frequency of collaborative forecasting and the efficiency of communication can be used to measure collaboration?

A: I think both of these indicators are OK. For external collaboration, I think the relationship between the supplier and you may affect the efficiency of collaboration. For example, if you work with a very familiar supplier and you have a good relationship, then you will have a lot of business transactions, and you often place orders with this supplier, so he may know what you may need in advance, and the communication cost will be relatively low. But if you do not always have interactions with some suppliers, your business transactions are less, the supplier does not know you very well, he may be very inefficient in all aspects of cooperation with you.

Q: This question is about sharing information. Do you think the indicators I've given can be used for sharing information in the supply chain?

A: I think the accuracy of a forecast can be used to measure the sharing of information in the supply chain. For example, if you need to make an order based on your stock information or something, they will check the company's stock through a software platform like some domestic ones, and then the customer will also make an order based on different situations.

If you're talking about uncertain probabilities, I don't think it's appropriate to measure shared information. I think you can use the accuracy of the shared information to measure it. Because not all shared information is accurate, you can think about it from the perspective of accuracy.

Q: For the factor of trust. Do you think these indicators can be measured, and if not, what indicators do you think can be measured?

A: I understand what you said about these indicators, but maybe some of them I don't think are properly described. For the confidential information sharing, I don't think this should be said that way. I think you can say share professional information in the supplier's industry, for example, information that he can get, information that he can't get from the customer's point of view. But you have to avoid letting him present confidential information, because confidential information may exist is such things as trade secrets, trade secrets, from this point of view, sharing confidential information is not appropriate. If it is information in the industry, your partner is willing to share it with you, which is good, that is to say, the degree of trust between the two sides is yes. The last one I think should not be a unilateral protection, I think this should be equivalent to belong to the cooperation of two companies, because of mutual trust, and mutually beneficial. Mutual benefit feels like a long-term partner.

In fact, you can also use the frequency of cooperation with partners to measure trust. For example, if you have a high frequency of business with your partner, the higher the frequency of business, the more you trust your partner, and you want to cooperate with him in the future because of trust.

Q: What do you think about the indicators I suggested to measure the risk management culture?

A: I think the reward and punishment mechanism regarding risk is not appropriate. Because you are now a factor in the risk management culture, then this is sort of a requirement of the position, and it is not valid for you to take this as a KPI to evaluate. I think if you are in this position you have to have a certain positive risk awareness to the next step of this position a judgment. I think managers have to be risk-aware, so this indicator can be used. Finally, I think it can be measured by the availability of training in risk management. Because if there is such training, it may indicate that the company is really focusing on this aspect of risk management culture, and then you feel that this is needed, so it is equivalent to doing a regular training for some professional knowledge or special products for some positions, and then let them do better to identify some risks of people.

Q: The next one is adaptability. Do you think the indicators about adaptability are reasonable?

A: I don't think the speed of redirecting requirements can be used to measure adaptability. I think the adaptability might be more of a company process, if the company has multiple processes that might be used to determine adaptability. For example, a company will have one process that is more than standard and then another process that is not standard. If you encounter changes, you will probably apply a non-standard process, which is equivalent to a company will build two different sets of capabilities, business processes. The next learning experience I think can also be used to measure, because I think this is to say that learning experience, and then accumulate expertise, perhaps more experience, you can quickly adapt to change.

Q: How do you think about supply chain innovation? Do you agree with the indicators that I have proposed? Do you think they can be used to measure innovation in the supply chain?

A: I think there will be changes in the development of the country or the industry, so your current supply chain process may not be suitable for the current environment. Then in response to such changes in the environment, you may need to innovate and redefine the supply chain process. For the indicator you mentioned, I think the culture of innovation is not very suitable, this indicator is rather broad, you say you want everyone to have a sense of innovation this is not possible. I think innovation in the supply chain is more difficult to measure.

Q: For the visibility indicators, do you think they can be used to measure visibility?

A: I think the indicators you propose out of the forecast error, the rest can be used to measure visibility. You can't use error to measure visibility, I think you can use whether this information is more readily available to measure visibility.

Q: I gave 3 indicators for the complexity of the organization; do you think these indicators can be used to measure the complexity of the organization?

A: I think it's very appropriate to measure complexity in terms of how many layers the organization chart has. But you said how many people are involved in one think I don't think is very appropriate. I think it's more appropriate to measure how many key people are involved in a process. For example, there are many people in a process to approve the decision, but there will be some key people in the approval process, and some non-key people. The non-key people may not be as important because they can be streamlined. So, in the whole process, if you have fewer non-critical people, the better the process will be for you. In addition, I think you can also look at the business overlap between departments to measure the complexity of the

organization. Because some departments in a company will overlap more or less. If the division of responsibilities between them is not clear, it may have an impact on the whole organization.

Q: Finally, how do you think about the indicators used to measure transportation efficiency?

A: I don't think you can use the customs inspection time to judge. Because this customs government machine enough, it is a fixed time when it is used as a link in the logistics and transportation.

When transporting products, you will choose a logistics attack company, so you can use the size of the logistics company to measure the efficiency of transport. Because it will have a criterion for judging your logistics.

For the export business, you will also choose a freight forwarding company, so for the customs side of the time, in fact, with the freight forwarding company is also related to the need to declare customs. Because the customs they have a fixed time, for example, when your things to the inside, how long they will be notified to your customs clearance unit, so that they apply for customs clearance, and then pay, and then take the goods away in the middle of this period of time, not sure if this is because the customs brokerage company problems lead to delays, so the efficiency of transport is also related to the customs brokerage company.

Finally, I think you can also use the integrity of the product in the hands of the customer to judge. Because the company in the middle of the transport, for example, some things, I mailed from this side is intact, to the customer's side know that the outer packaging is broken, something damaged this situation.

Participant C1

Q: Can you tell us about your company's background?

A: Our company is a manufacturer of medical devices, and our head office is in the United States, and our products are sold worldwide. And then the Chinese company is mainly in charge of the Asia-Pacific market. Our products are mainly produced in the United States and Europe, so we are actually a receiver for the Asia-Pacific side, so the goods are mainly sent from the United States and Europe. The Chinese company mainly needs to receive the goods, but our supply chain side has three distribution centers worldwide, one in Europe, one in the United States, and one in Singapore.

Q: For agility, which you believe is very important, do you think the time to respond, the time to access relevant data, and the time to detect threats can help you assess the agility of your supply chain?

A: In fact, although I am in charge of the logistics part, I have communicated a lot with the staff of planning, and they have indeed considered a lot of situations, but there are really some things that we can hardly predict. For example, as I said before, all of our products are made in the U.K. and the U.S., and we are only the receiver in Asia Pacific. But a packaging supplier in the United States changed the origin from the United States to China, therefore the American company asked the Chinese company to assist them in importing packaging materials from China to the United States and to Europe. We therefore help to consult the price of transport, but because we have no previous experience of export, we mainly import, we just do not have a very comprehensive understanding of the export of China sea freight, inquiry found that the price of sea freight is very expensive, and finally compared with the choice of a cheaper. But the shipping market is very unstable recently, and the position of China to other countries are very difficult to change, it is unusually difficult to find the kind of situation. This leads to even now this vote has not considered the price, but the transport still need to wait. This belongs to a situation of not knowing the situation of the ocean market and not predicting the possible situation, which leads to not reacting even when there is a problem. At present, the news from the planning department is that we are about to back order. immediately into a new month, we plan to let a small number of orders go by air first, to avoid the situation of delayed delivery. But at present, due to the special situation in China, recently there are regulations that oversize products cannot go by air, so at present it is not possible to do it by air, so we can only ship this product out after July 2nd. The main reason for this situation is that we do not have enough understanding of the situation of the sea market, as well as the special domestic regulations, so we do not have a sufficient response time. But this may be related to the company's business, because it really has not been in contact with the export work content before, so it is not very familiar with the workflow. For example, the transportation of dangerous goods has been banned in China since June 20th, but our main products contain dangerous materials, so our suppliers are now out of stock. But we have no choice, because the notification time June 18, so June 20, and then take action is basically too late, and now we also have to wait until after July 2 before we can ship. Well so I think there may be a correlation with agility, but we are more reactive in this piece, because this is not a problem that we normally have to think about. It's you know the Suez Canal ship blockage and then we had a shipment that was blocked in that and then it wasn't until later that it was delayed for twenty days anyway, but it wasn't delayed particularly long. I think we would have done better if we had predicted it in advance.

Q: Collaboration you also think it is very important, so what are your thoughts on the measurement metrics of collaboration?

A: Actually, I think all three indicators are quite good for collaboration, there is no problem. In fact, when I received the news that the dangerous goods could not be transported after the 20th was on the 18th, I thought this news was important for planning, so I forwarded the relevant information to the relevant staff of planning. But planning seems to have missed this information, so they did not take action in advance, which led to a consequence that the dangerous goods could not be transported to the customer, nor could they even be transported from the airport to our own warehouse. One of the problems here is that the airport warehouse

is priced differently than other places, it is paid by weight and number of days, so you can predict that the bill will be very high this month. I actually think this example is also somewhat related to information sharing. From a collaboration perspective, although I sent the information to the relevant department in advance, I did not alert them in time to follow up on their feedback. Planning may have missed this information, thus leading to this very awkward situation. This is a problem of collaboration between two parties. This problem is mainly a problem of efficiency in communication. For example, our company, for example, the goods import company needs a customs broker, and then at the same time our relevant departments and their relevant departments are required to collaborate, that is, this related information will be in the middle of their round trip many times, in the middle as long as there is a link delay or problems, and then it will lead to the import of the time limit growth.

In addition, mentioning customs declaration, I also remember a problem, that is, the master data of our company's SAP is not quite accurate, the weight of the shipment is not accurate. In fact, weight is a very important issue in customs or international shipping. Our previous single product has caused some problems because of this inaccurate data. The shipper should have filled in the actual weight in the invoice, they should have weighed it themselves, but they didn't, and then they just used our wrong weight data. So when the Chinese customs found out that the goods stated on the invoice as 7 tons were actually weighed out as 14 tons, then they suspected that we were carrying other goods. This led to these goods being held for more than a month, and the people involved kept going to customs to communicate and then produce relevant certificates, which caused a lot of trouble.

Q: I think you have a problem here with sharing information or about the accuracy of the information.

A: Yes. As far as we know, some of the weight data from the U.S. head office is still inaccurate. Although we have given feedback on this, the data in the current system is still not correct. And Chinese customs is the most serious about this, so other countries receive the wrong ones they can also be included, but here in China is particularly strict card. In fact, customs are not very exaggerated, that is, your weight within 5% floating in fact are acceptable, but we are too much to check. The service of the freight forwarder we currently use is particularly poor. This is because there are often cases where the incoming receipt shows arrival, but the goods have not yet arrived. And its weight is always not over the scale, he fills in whatever weight is on our invoice, but our invoice is net weight and he writes the net weight directly on their gross weight. Wrong weight is dangerous, for example, if you choose air freight, you say you this is for example 300 kilograms, and then you this actual weight of 600 kilograms, in case people's planes fly to give crooked or what, in fact it is really risky.

In fact, different countries and regions, its rules and customs are not quite the same, all levels will be involved in such problems. Perhaps I said before the weight issue for most countries is no problem, only a few countries will be particularly strict. For example, China may be more concerned about the accuracy of your letter declaration information. But Vietnam is very strict, requiring all information to be identical, and its end customers also need to see your import declaration. And then there are some of these that may be more related to the document information or the accuracy of the document. For example, some countries may require your legal name or legal addressed to be exactly the same before you can. Then he may have some other reasons that customs may not be so reasonable, for example, maybe Thai customs, I heard that some of our goods have been detained for more than a month, they do not square line, but we do not know what the reason is. This is the customs may not be particularly cooperative, these may also be we cannot predict.

Q: Actually, I think you've talked about information sharing above, and now we're going to talk about metrics for measuring information sharing. Do you think these three metrics that I've listed about sharing information are appropriate?

A: In fact, I think what you listed is quite good, but I had thought that you might show me something like a KPI that can be quantified, but I also think that this kind of thing may actually be really difficult to be

quantified in the work. For the inventory management efficiency indicator, my understanding is that for example, when we ship, especially for example, like the international section of the transport, as long as you ship, we may have an early warning, to the local, that you may have about what goods are ready to send out, so when the goods are sent out, they can receive a notice that which goods will come. Next is when the goods are sent out, for example, from Singapore to Taiwan, there is an inbound delivery in the SAP will be automatically created. So, CPL will check this report regularly, and when they see a new inbound delivery created, they will know that a new shipment is coming. They also know the specific batch and the quantity, and all the information is notified both in the system and in the mail. And then at the same time planning will also send a TRACKER regularly, once a week, and then mean what products may be on the way at the moment, and what new products we have ordered. So, I don't think I know, I don't think it's particularly necessary for this inventory management efficiency. Because we haven't received any feedback that there might not be enough inventory space, only very occasionally they will have a stock blowout, and they will tell us what kind of risk you might have with the recent blowout, but basically, it's a small risk.

I also thought of one more thing. We have a product that has humidity requirements, so it has to be put in a drying cabinet. Some warehouses will have a drying room, the whole room has humidity control. But there are some countries it warehouse does not have this function, so we can only buy drying cabinet. But the drying cabinet it has a capacity limit, so if planning once ordered too much goods, the cabinet will not be able to put. So, this may be the information we will give to planning in advance. you can know the most can be in the preparation of how much inventory, because you then more this cabinet cannot put. I also think of another point, for example, our products in the warehouse before the first to do quality control, and then do quality control or to say labeling, and then are not directly by the CPL to do. QA may need some approval, or he found some damage or need engineers to install something, he sent an email to us, but we did not reply in time or reply but they did not coordinate well, this will indeed affect the business. This seems to be not quite inventory management, but belongs to the efficiency of communication.

Q: I'd like to ask you what you think about the indicator of the efficiency of communication?

A: The effectiveness of communication is measured by response, for example, replying to information within a day. Usually, the response rate is used to measure, for example, the time to receive an email or receive a notification, and then the execution is completed. This time can be calculated, because they operate on the system, for example, they will have data evidence, so they will have responsible, have a monthly KPI.

Q: The last indicator is the probability of uncertainty, what are your ideas about that?

A: I think it makes sense. In the early days of the time may not know much about this thing, because he also did not set down, Lead time will be set a little more. When the back of the special circumstances experienced a little more, probably how long late what, we will also have more in mind. But indeed, I think to may have you know more, so your prediction will be more accurate situation. But this time, if there is an unexpected situation, it may lead to back order, recently the market of air freight seems to be very unstable, so I was in a meeting with the freight forwarders, I asked them to say on air freight you cannot give us a copy of the standard lead time between each country or each port. But they said that since this year, they have not given it to the customer, because it is useless to give it, and especially the sea freight. For example, its ETA will be postponed for a month without knowing why, during which you will not be notified of the postponement, except to go to the website yourself, and then you will be horrified to find that the ETA is postponed for a month.

Q: The last enabler that you think is very important is visibility, so what are your thoughts on the indicators given for measuring visibility?

A: I think Information technology can be visible, because our company is currently doing the transportation track system. why do we have to make this database? Because our current SAP does not contain the module of transportation. For example, after the goods come out from original warehouse, it is equivalent to the

system inside is already shipped. Then if it is STO, there will be a destination warehouse, and when the goods are received, it is the time when this thing needs to end. But the time required in between may be different. For example, by air, it may be seven or eight days, and by sea, it will take 30 to 60 days, so we have no way to visualize where we are in this period. So, we have such an idea, and then made such a system. Currently this system is running down actually feel pretty good quite useful. Because our company is still a new company, planning needs to use the special planning system has not yet come out. Then they actually have some they are relying on excel to do forecasting, to maintain the data to determine which received goods, which did not harvest the goods. Then now, after having this at least to replace their manual check of each vote and other time.

Q: Regarding the ease of access to information, do you think this indicator can measure the visibility?

A: We have regular monthly KPI meetings with the CPLs in each country to get information. In this meeting, in addition to the KPI meeting, we will also discuss this month or in this quarter, our company in logistics or in what other areas to do what improvements, or what adjustments, and what adjustments we have made with the CPL in the middle of the month, and then need their assistance, including if they have some strategic adjustments, or that They have a new service scope, they will also let us know. For example, we will be introduced to the current import and export of these is what kind of situation, and then our company in your company with these goods is how the performance, and then in the industry is what kind of situation, and then our volume of goods anyway we will have regular such sharing.

Q: What do you think about the proposed measurement indicators for supplier disruption?

A: If you're talking about spare parts suppliers, my job probably doesn't cover that situation. But I know our supply chain is always looking for new opportunities to adjust. As I mentioned before, most of our products are now made in the U.K. and the U.S., or in France. The current situation is that their prices are high and they love to strike. So, the company may consider building a factory in China afterwards, and then look for more qualified suppliers who can also make the same products. In fact, from the source revenue point of view, the Asia-Pacific side of China and Japan is the largest sales, but all our products from the United Kingdom and the United States, in fact, from the cost point of view is the idea, but now the bosses are still doing discussions, the specific time down is not known.

Participant A5

Q: The first question is about leadership, which you think is important for supply chain resilience, and here I have provided three main indicators of measurement, do you think they are applicable in practice?

A: In terms of leadership, I think all the decisions you make or the programs you want to implement need to be made by a person who is going to make the decision. I think this part is to have a very wise leader or to be able to have a big picture view, he can look at the whole picture to see whether the project or event can be implemented. I think this is very important, otherwise many things will be in a state of suspense, otherwise no matter how good the idea, without the decision and support of the leadership is not implemented.

Q: Next is about agility, you also think agility is very important, do you have any opinion on the indicators of agility?

A: I have heard a lot about the word agility in the recent years, and the company I am currently working in has been talking about agility. It actually refers to the ability to respond quickly to some requirements and to make changes in the process when there are some changes. At the same time, we also hope to solve some process problems through some agile methods. I think agile should actually be able to respond quickly, get information quickly, and respond to threats quickly, and this is a sense of agile. For example, why do you need to be agility, and then how to achieve it, I think these three indicators are a little bit this meaning. But I think it is not so comprehensive, that is, agility cannot only be measured by time. Because sometimes when you make some process changes, it may take some time in the early stage. Because it needs to turn some of the previous process things completely upside down, or have an idea, you are slowly going from nothing to is slowly advancing, the preliminary time spent longer, but it brings the result is that it brings the result is very let you become more efficient. If you can judge from time completely from time, I will feel a little incomplete, because it is not only reflected in the length of time. It's the third indicator, for example, the time to anticipate danger. But I think it is more to be able to make timely changes when some risks appear. Because using time to determine the effectiveness, it is a process of quantification, in fact, is more effective, but I think only using time to quantify the effectiveness may not be enough. But this is just my personal opinion, because I think the word content is actually quite a lot, and then there are some differences in personal understanding. But if it is to quantify to measure agility, I think it is okay to use time to judge, there is nothing wrong. For example, you can consider how many projects related to agility you have done in a year, and I think that is also possible. From the number of projects, including then for the project to make some evaluation. Because after you do the project, you always have to evaluate its effectiveness.

Q: The next question is about supply chain collaboration. The first one is the frequency of collaborative forecasting. Do you think it can be used to measure collaboration?

A: How do you understand collaboration as collaborative forecast? What is the concept of collaborative forecasting? Is it the possibility of collaboration?

Q： Collaborative forecasting here means that you are forecasting in a way that requires external collaboration or collaboration from different departments internally, so the measurement is whether you are taking collaborative forecasting often when forecasting. This is either the possibility of collaboration or a method of forecasting.

A: This indicator doesn't seem to be available to us very often.

Q： The next indicator is the effectiveness of communication. Does this indicator measure collaboration? Here I think we can use response rate, for example, you send an email, and then what is your response rate, I think this will be clearer to quantify.

A: I think it may have to mention different ways of communication. Because there are different ways to communicate in the workplace, maybe by phone or face-to-face. But if you want to talk about efficiency, I think the phone or face-to-face or having a meeting is more efficient, if you want to do some decisive communication. For supply delivery efficiency I think it is more of an indicator of the significance of the decision. In fact, the cooperation is pre-determined, it is already a contract or an agreement, so the other party must be in accordance with our pricing requirements to support the. So, I think this and you, your later collaboration cooperation, the impact is not very big. But it's not that there is no relevance, the cooperation can be with the supplier or with our customers. When you encounter problems, or encounter some bottlenecks, it is this kind of friendly cooperation can help you solve problems quickly. But with this side you say the supply deliver efficiency I think is not very relevant, but effective cooperation can help to quickly solve some problems. I think this is useful.

Q: The next one is sharing of information. The first indicator is the accuracy of forecasting, the second one is inventory management efficiency, and there is a probability of uncertainty, what do you think about these indicators?

A: I think information sharing can improve the effectiveness of communication. Because I think when all your information is transparent with everyone, your communication cost will be lower, which means your communication efficiency will be higher. This way you don't need to ask over and over again, and you can shorten the frequency of communication or reduce unnecessary communication. Regarding the efficiency of inventory management, I don't think it has much to do with information sharing. But the transparency of information can certainly help to do some forecasting better. The last possibility of uncertainty, I think this is okay.

Q: Let's move on, the next enabler is trust. Also, three indicators, as you can see in the table given to you, what do you think about these indicators?

A: The first one is the time we have been cooperating with the customer, and if we take a look at the supplier side, it is the length of time we have been cooperating with this supplier, right? If you quantify it, you can see a problem of the length of cooperation with our customers. The next indicator refers to some changes in the industry, or that the supplier will continue to share with you some information about his subordinate suppliers, when his subordinate suppliers have some problems, to be able to timely feedback to our side. I think this one is also an indicator based on trust. Both confidential Information sharing and the third indicator are acceptable. These two indicators are not quantifiable, but more descriptive.

When your end customers have some problems, they can communicate with you in a timely and truthful manner. When your suppliers have problems, you can also work together on the basis of trust to solve the problem. These three indicators are more of a feeling of trust between business and business. Your company body and your other company body, that is, your customers or your suppliers between a relationship, but if you narrow it into the scope of refinement to the internal words, you can be divided into two parts, part is just said between the company and the company, between the company and the supplier, between the company and the customer is a big together, the big subject to look at the issue of trust. The problem of trust. If you want to supply chain internal, because each person inside the supply chain is actually an important carrier, it is a small carrier, but if between employers and employees, between the team and the team, it is also necessary to often be able to maintain some information communication, because the supply chain inside some internal processes or quite fine, so each team and team between the trust is also very important. When a crisis arises, you as a large supply chain under a whole to see how long it can be to deal with the risk, this time is dependent on the supply chain as a whole under the other small function between a trust. I think the internal words are basically how you say I will believe you; external communication may be a little longer.

Q: The next one is a discussion about risk management culture. What are your thoughts on risk management culture? How do you measure this risk management culture?

A: This has a risk, assuming it's a customer complaint, because a complaint is a risk for the supply chain. Assuming the client side, for example, customer complaints, we have a team who is specialized in handling customer complaints and need to give a survey result within three days, something like this indicator it is there, or you have to give a basic reply within 24 hours, you have to do Ming to make a clear survey result to the customer within three days, this kind of requirement is there, and it is quantifiable.

If we talk about the other side, another risk is the risk of product quality. Because many of our goods through the transport over, from foreign countries to the domestic, many times there will be some risk of damage, or a variety of risks. This kind of quality problems, the warehouse side or the transport side also need to make timely feedback processing, he should also have KPI's, I need to do the investigation within how many hours, and then into the warehouse, this part is also quantifiable.

I think it depends on how your risk is defined, because the risk is still very broad. So, I think you have to define the risk. In my opinion the risk of breakage is all part of the risk, to the quality of the risk in all aspects is risk. If you can define it to be specific, you can pick some metrics to measure it.

Q: Next is adaptation as an enabler. Adaptability can be measured using two indicators, what do you think of these two indicators?

A: The speed of repositioning requirements, I think it is acceptable. For learning from experience, I don't think you should just talk about learning from experience. It should be specific to the learning to do the record, archiving, and even programming process of some things, from the process end to improve. I think you can be more specific. I think it's too broad to say learning from experience alone, I think you can be specific to write into a working instructor or write into a or even write into a sop. let it become a real guidance document, not just talk. How to share this experience after you have it internally.

When the whole situation changes, for example, like the time of the epidemic last year, you're is the whole international environment changes, your international transport flights are not all stalled, how do you go to the rapid and effective use of resources to solve some of your current problems, on the integration of resources. That is, when the external environment changes or some policy-oriented things change, how do you quickly adjust the supply chain strategy to meet the needs of the end customer.

Q: The next enabler that you think is very important is innovation. There are two indicators mentioned here to measure innovation, do you think they are appropriate? Also, do you have any other suggestions for metrics to measure innovation?

A: I think to have a mindset, that is, everyone in the team should have a creative thinking idea. When you face some unreasonable situation, you should be brave enough to think about change. From the company's culture, it does need a culture to promote, when your entire company's culture in the emphasis on innovation, more or less will also affect each of us. The company can also provide some corresponding training, these training may be some work skills training, or some cultural aspects of this training, or some kind of regular organization of some industry-leading information exchange meetings. How many professional forums are held in a year can be used to measure innovation? Then, the number of innovative ideas proposed by employees in a year can also be used as a measurement indicator, because these ideas you can quantify. For example, in a year, a team of 1,000 people put forward a whole 3,000 ideas of innovation in this area, this part can be quantified. These ideas are quantifiable, the percentage of ideas used. Or how much efficiency it really brought to the company. This part is also quantifiable. From the larger aspect, one aspect is the influence of the company's culture to promote, some industry something to share, and from the company level to influence each employee personally, and then join the culture of innovation, this is can be used to quantify the indicators.

Q: The next enabler question is about flexibility. What are your thoughts on flexibility?

A: Spare part supplier rate, this indicator can be considered. We think a lot of things have been mentioned before, flexibility, agility I think are actually relevant. For example, I prepared 5 stocks for material A in China, and I consumed the 5 before my required replenishment time, so I didn't have any zero stock. That is, the hit rate is 100% of how much I have prepared for you, and I just happen to consume so much in this month. For example, if I gave you 4 products ABCD, and you didn't use any of them, and you didn't use any of them, it means that the hit rate is very poor.

Technical flexibility, that is, when you a product segment on his technology updates, your side of the supply chain you can make timely response. Because after any technical update, you need to communicate with the technical team. We also need to prepare the inventory in time, so that we do not have the technology update, we can no longer meet the customer, this side needs a good cooperation with the technical team, including a good cooperation with suppliers. Considering that it is related to our supply chain, we also need to cooperate with various technology updates and prepare our inventory in a timely manner.

Q: The last question is about visibility, what is your opinion on the visibility indicators?

A: Information technology represents some transformation brought by technology. I think here visibility can also be considered, supply chain you not only with the external, your own internal also need to have a KPI, how you can easily read to all aspects of this information, the original words we may be like you say we use Excel it is encrypted, I send to the boss each time a person to see or encrypted, if the boss wants to share with others, there may be an email is again transferred.

But if through the new information technology, now with BI or is business intelligence this kind of platform to do a professional data platform, is he convenient to help you to read some of the information you need, your unit KPI or is the degree of completion of this way. From another aspect, there is, for example, our warehouse inventory management often use the kind of Kanban, the previous Kanban is a board, to reflect the inventory of the activities of a situation. Now many are using an electronic board, it is actually a large database behind. When you make changes to some information corrections, he can see very quickly you can see the background in the refresh. For example, how many inventories you entered that day, how much inventory you sent out that day, but the data bar is always changing, then it is very convenient for everyone to do some planning, or to make some adjustments. You cannot use Information technology is part of, you now more units is the enterprise with digitalization is more. Can you can say again Information technology behind the research brought digitalization.

Participant D1

Q: What is the specific business of the company? I know that the company is a small and medium-sized private enterprise, is your company involved in the business of import and export?

A: The company is a private enterprise, engaged in the production of medical equipment. The medical equipment includes ultrasonic bone density checker, osteoporosis treatment instrument, etc. The company is having import and export business. And our company also has after-sales, with professional after-sales staff.

Q: I have seen your questionnaire is written about the perception of leadership and that this enabler is very important for supply chain resilience, so may I ask how you assess or measure the leadership in your supply chain?

A: The leadership we can consider from the perspective of sourcing. The proper operation of the supply chain requires sourcing, and sourcing requires frequent communication with suppliers. If the leadership is not good, management is not strict, and leadership is poor, sourcing will be slack and relaxed to cope with the situation. For example, for some of the required equipment, sourcing may not want to choose the best and most suitable, they may sometimes choose other products to save money. But it is possible that the product is not the most suitable for the company, but still spend a lot of money, which will cause a loss to the company. So, for this area, it is necessary to increase leadership, to strengthen the leadership and management of this piece of procurement, including the motivation of employees, so that the procurement staff in the procurement of the choice of the product is not necessarily the most expensive, but must be the right.

Q: The next question is about agility, and then I know a lot of companies are emphasizing agility in particular nowadays, especially in these years, and I would like to know how do you assess the supply chain agility of the company you work for?

A: I think agility refers to the mechanism of our company's reaction speed to sourcing. For example, in the upstream side of the supply chain for some products, the market has already given new trends. According to the demand of the product, there is already a demand trend, and it should be produced quickly to meet the market demand of this product. At this time, the company's supply chain needs to quickly adjust to changes in the required materials, so that you have to change quickly. If you are there if the response is slow, then the market may be other products to adapt to the market after all out, you have to think about the problem, it is too late to occupy the market in time. If there is no product on the market, then the company is not much competitive in the market, so the agility of rapid adjustment is too critical.

Q: For collaboration, what indicators are used within the company to measure collaboration in the supply chain?

A: I think collaboration is also a very critical part, where the efficiency of communication is very critical. For example, when purchasing a raw material, the company needs to send a technician to inspect and accept the product and make a practical inspection of the actual test. In this regard, the raw materials that meet the company's requirements can be selected from many products, and then it is necessary to communicate with the company's sourcing staff as soon as possible, and the sourcing staff will go to negotiate prices with the suppliers. But the sourcing staff may not have strict control over the quality, control is not good, so the sourcing staff need to communicate with the inspector in a timely manner. Therefore, the communication between sourcing and inspectors is a very important link in the supply chain, so the communication efficiency is too critical, that is, your timely communication and timely procurement is an important link. For the quantitative indicators of communication, we use the staff generally about how long to work with each other, in fact, our general requirements are the same day to dock.

Q: The next question is about sharing information, which you agree is very important, and what indicators do companies generally use to measure sharing information?

A: For sharing information, what I think of is just like the company's internal management with management software, basically equivalent to technical staff, procurement staff, bargaining staff, including payment staff, including logistics staff, etc. All these links are not missing, they must cooperate with each other to strengthen the sharing of information and enhance communication. For example, there must be a docking between quality inspection and procurement. The information between procurement and finance also needs to be usual, and finance needs to pay for goods, so it needs to dock with procurement and reverse line. Especially when the company does not have enough goods in stock and the goods to be purchased have been accepted, then the finance staff needs to hurry up the payment, otherwise it will have some impact on the operation of the subsequent supply chain**.**

Q: For the supply chain risk management culture, from what aspects do you generally observe the status of your company's risk management culture?

A: If a company is not well managed, there are cases where some technicians are bought or jumped, or the procurement staff receives benefits from them. Although the price is negotiated by the procurement staff, some middlemen will take advantage of it. Therefore, I think that in the risk culture, these risks should be avoided, and after the risk management culture is established, all these potential risk problems will be solved. They will not think about these problems anymore, and this is very good for the development of the company, so this is also very important.

Q: The results of the questionnaire showed that you think innovation is also a very important enabler for supply chain resilience, how do you measure the innovation in your supply chain?

A: We can explain this issue from the innovation of the supply chain system, for the procurement of supplier selection, our company has a set of systems on the selection of suppliers, from its production process, personnel tax company loyalty, or tax indicators, which is a kind of assessment of suppliers. But the system of selecting suppliers should also be adapted to society, the environment changes at any time, some parts of the existing system may slowly become no longer appropriate, some places to delete, or add some new content into the selection system. For example, the company's selection system may start with a total of 8 factors, but later changed to 3 factors through innovation. The supply chain of medical equipment is not static, so there should be continuous innovation to choose a better and more suitable for the direction of the company's production.

Q: The last question is about the flexibility of supply chain. You think flexibility is very important, so what is your opinion about flexibility?

A: This should be very good to grasp, flexibility is mainly three aspects. The first is the flexibility that affects the procurement. In the procurement process of the company, there may be special circumstances in the handover of some procedures, so it is necessary to have the flexibility to deal with special circumstances. In addition, there is also the flexibility of logistics, for example, to obtain normal transportation by land, which takes three days to arrive, but if there is a sudden emergency, the logistics may become air cargo. So, you need flexibility in your supply chain, and you need to be flexible in changing the mode of transportation so that the goods can arrive as early as possible. Another thing is about the upstream suppliers, the suppliers have their own shipping system. But there are some special cases, because the products are market-oriented. If there are special circumstances, the supplier has to make quick adjustments. For example, in case of an emergency, we place an order outside of working hours, but the order has to be received tomorrow. Then this time it is necessary to negotiate with the supplier to try to send the order on time, then it may be necessary for the supplier's staff to work overtime to complete the order, so flexibility must be needed for everyone.

Participant A7

Q: Why do you think agility is very important? And what do you think about the indicators used to measure the agility?

A: First of all, my understanding is this, that is, the agility in the supply chain resilience refers to the supply problem, he can quickly make some response, so I think one of the factors in the question is to have a timely response, he must quickly make a response. Especially like the previous epidemic, which did lead to problems in the supply chain. For example, like our company, there was a problem during that time, the first supplier side had a shortage of resources, because the personnel could not be in place, and then the raw materials could not be in place, this time the whole organization needs to solve these problems in the fastest time, so I think agility is still quite important for supply chain resilience. I think the measurement indicators you gave here are quite comprehensive, one is the time to detect the threat you mentioned, agility makes it possible to find the defects in the supply chain operation as soon as possible. But this defect problem is dependent on several aspects, if the threat is caused by natural disasters, it is difficult to know. But there are threats that can be detected through, let's say, experience. Through experience you can react as quickly as possible, and then you can also quickly determine where the problem is, and then we can discuss how to solve it, so I think agility is still quite important to supply chain resilience.

Q: The next question is about collaboration, why do you think collaboration is also very important?

A: I think when there is a problem in the supply chain, all the people from top to bottom need to work in one direction. For example, during an epidemic, there is a problem on the supplier's side, the supplier's staff is not available, and the raw materials are not available. At this time, as a procurement needs to contact the R & D, contact production, and even contact the front-end customers, through communication and collaboration, the customer's order will be a priority level. Secondly, communicate with R&D department to see if there are any new and alternative materials to replace the shortage of spare parts. Finally, we need to communicate with other suppliers and ask if we can do a support. So, this time to body out the importance of collaboration. The support from the boss is also very important, because if the boss does not support this matter, then it is difficult to promote things, so I think collaboration is still quite important for supply chain resilience, to enable the supply chain to quickly return to a normal level.

Q: What are your thoughts on the efficiency of communication as an indicator?

A: I think in the actual work, we will assign tasks to each person during the meeting, and we will discuss and determine a specific completion time through continuous communication, and we need to finish the tasks within this event. If we want to quantify the efficiency of communication, for example, how much time it takes to give a reply to something at work, I think different cases are different rules, because the difficulty of each task is different. For the measurement indicator of collaboration, I think we can perhaps consider the effectiveness of each meeting. Some meetings may be very effective in solving problems after discussion, and some may not have any results after discussion. And some meetings can be done in 30 minutes and all the problems can be fixed quickly, but some meetings need to be held for an hour, but there is no clear result at the end. An effective meeting means that each person is clear about where his or her responsibilities lie. For their own tasks, they can complete them on time and know clearly what their tasks are, and they can clearly explain the progress of their tasks in their communication with others. If the task is not clear, people feel that it should not be their own task, then this is the meeting may not be effective, because even if the task is given, people will not be completed properly.

Q: For sharing information, why do you think sharing information is a very important enabler?

A: I think we can discuss trust, collaboration and information sharing together. Collaboration is actually based on mutual trust and then sharing all the information with all the staff. That's how you can show that

your collaboration is effective. Then trust and share information, if the shared information is not accurate or incomplete information will affect the subsequent decision, and even the judgment of cross-departmental functions will be affected, so I think it is important to share information in the supply chain. Because it can be said that sharing information is the foundation, with this foundation, the supply chain can collaborate, and with collaboration to solve problems in the supply chain quickly after they occur.

The accuracy of forecasting is an available measurement indicator, for example, forecasting is like this, the people who have the information are willing to share the information to help forecasting. If there is a SOP meeting in the supply chain, that is, a collaborative production and marketing supply chain, the SOP meeting needs to be attended by sales, production, R&D, and even all the people in procurement and supply chain positions. Then everyone will share their information and make forecast based on all the information, and then the forecast will be compared with the actual data of each month to compare whether the forecasted data is a lot worse or more or less. If there is a big difference, we need to analyse why there is a big difference. In fact, these forecasts are made based on the information you share, and you can only make forecasts based on the correct information given to you by people in each department.

Q: Finally, you also think trust is very important, so can you explain why?

A: I do think that trust is actually really true. I think this indicator of the length of your relationship refers to the length of time you've been in contact with people, right? But I think the length of the relationship is not only because of trust, I think in the actual case, we may have some other problems will lead to this relationship duration, for example, the price factor, if the supplier's price is higher, we think it is not suitable, we may not continue to cooperate with them. If the supplier, let's say, has a good attitude of cooperation, but he but if you have a good attitude of cooperation, including his ability to give us regular price reductions, I think this is certainly sustainable business.

I think the indicator of sharing confidential information in the industry can be used to measure trust. I think trust is judged by behaviour, for example, in procurement, we will classify suppliers, some suppliers are our strategic partners, strategic partners are what we call Strategy supply, which is actually the most priority level of suppliers, this level of suppliers, we do not only say that the two sides of the senior management will communicate, which will definitely involve some of the suppliers, such as the top management of the company. It will definitely involve some confidential things. Let's say our company's future development plan is like what, the company's senior management will share the information with this supplier, and that supplier because that supplier he also needs to match with our company's development prospects. For example, let's say the printer business. The company originally needed to use all the printing, paper materials, signatures, so there would be a lot of paper. But then the company's rules changed, the company will not need all the paper printing, all need to sign online, so the demand for paper will be less. At the same time, it will need some other support, so the company needs to share a company-wide development plan with its partner suppliers. This will enable the supplier to adjust their own direction in a timely manner, including his stocking, for example, he may have to give you a certain amount of stock, but now the company no longer needs paper, this will not have to stock. But the company may also need other things, you then the supplier's own production plan also needs to be adjusted. As a strategic partner, we are a state of trust, if I do not trust each other, I will not be able to supply this as a strategic partner. If the company does not trust the supplier, then it will not give the supplier the corresponding business, so trust is still very important.