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RESILIENCE OF FINNISH MANUFACTURING SUPPLY CHAINS DURING THE COVID-19 PANDEMIC

Master of Science Thesis
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ABSTRACT

Heikki Turja: Resilience of Finnish manufacturing supply chains during the COVID-19 pandemic
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These days' many supply chains, especially in manufacturing industry, are very global. Components and materials can be bought from tens or hundreds of different locations around the world. This has many benefits, perhaps the biggest one being better cost-effectiveness. It can, however, place the supply chain in a more vulnerable position, because disruptions on the other side of the world can risk the supply of those needed materials and components. The COVID-19 pandemic is one good example of a global disruption that put supply chains under pressure. The effects of COVID-19 on Finnish manufacturing supply chains are the focus of this thesis.

Supply chain resilience means the adaptive capability of a supply chain to prepare for and respond to disruptions, and to make a timely and cost-effective recovery from it. In this thesis, the goal is to find out what are the building components of supply chain resilience, and how it could be improved. This question was answered in systematic literature review, and 16 elements of resilience were found. These elements are categorised in three groups in this thesis, and their interactions and effects on one another were examined. Furthermore, methods to improve each individual element were investigated.

Another goal of this thesis was to find out what is the state of supply chain resilience in Finnish manufacturing industry, and what was the role of the resilience during the pandemic, and what actions and reactions the pandemic caused in firms. The empirical part of the thesis is focused more on answering these questions. Four Finnish firms were interviewed as part of this thesis. The interviews were analyzed, and with the help of the constructed framework, the components of resilience in each firm were evaluated and rated. The ratings are used as an analysis tool to help in making conclusions.

The most important results in the theoretical chapter of this thesis are finding the structure of resilience, its building elements, and their interactions between each other. The findings also suggest that the most important elements of resilience are collaboration, flexibility, and agility. In the empirical part, the findings also support the constructed framework of resilience and the interaction between its elements. Another finding from the interviews was that in the interviewed Finnish firms, the reaction to the pandemic was mainly increasing preparedness, increasing emergency stocks for materials and components, and moving to closer and more frequent communication with business partners. The findings in this thesis also suggest that the industry of a firm might have a big impact on the level of its supply chain resilience, but the validity of this finding is relatively low with this sample size. In the end of the thesis, each of the interviewed firms are given some targeted guidelines on how their supply chain resilience could be improved, and these guidelines should be viable also for other firms in similar situation. Furthermore, some general methods for typically efficient ways for improving supply chain resilience are given.

Keywords: Resilience, supply chain, supply chain resilience, pandemic, COVID-19, supply chain vulnerability, disruption, supply chain management

TIIVISTELMÄ

Heikki Turja: Suomalaisten teollisten toimitusketjujen resilienssi Covid-19 -pandemiassa
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Monet teollisuuden toimitusketjuista ovat erittäin globaaleja. Komponentteja ja materiaaleja saatetaan ostaa kymmenistä tai sadoista eri paikoista ympäri maailmaa. Tästä on monia hyötyjä, suurimpana sen tyypillisesti tarjoamat matalemmat kustannukset. Tämä toimintatapa kuitenkin asettaa toimitusketjun haavoittuvaan asemaan, sillä häiriöt myös toisella puolella maapalloa voivat vaarantaa materiaalien saatavuuden. COVID-19 pandemia on yksi hyvä esimerkki tällaisesta globaalista häiriöstä, jonka vaikutuksia Suomalaisten yritysten toimitusketjuihin tässä työssä tutkitaan.

Toimitusketjun resilienssi tarkoittaa tiivistetysti toimitusketjun kykyä valmistautua ja reagoida häiriöön, sekä palautua siitä kustannustehokkaasti ja ripeästi. Tässä tutkimuksessa tavoitteena oli selvittää mistä komponenteista toimitusketjun resilienssi rakentuu, ja miten sitä voidaan kustannustehokkaasti kasvattaa. Tähän haettiin vastausta systemaattisessa kirjallisuuskatsauksessa, jossa löydettiin 16 komponenttia, joista toimitusketjun resilienssi muodostuu. Nämä komponentit luokiteltiin kolmeen ryhmään, ja niiden väliset keskinäiset vaikutukset selvitettiin, kuten myös eri menetelmät yksittäisten komponenttien parantamiseen.

Toisena tutkimuksen tavoitteena oli selvittää mikä on toimitusketjun resilienssin tila Suomalaisessa valmistavassa teollisuudessa yleisesti, mikä rooli resilienssilä oli pandemian aikana, sekä miten pandemiaan reagoitiin eri yrityksissä. Tutkimuksen empiirisessä osiossa keskityttiin vastaamaan näihin kysymyksiin. Työssä haastateltiin neljää Suomalaista yritystä aiheeseen liittyen. Haastattelut analysoitiin, ja teoriasiossa rakennettujen työkalujen pohjalta haastateltavien yritysten resilienssin komponenttien tilat pisteytettiin. Pisteytys toimi analysointityökaluna, jota käytettiin johtopäätösten tekemisessä apuna.

Työn tärkeimpinä löydöksinä ovat teorialuvun resilienssin rakenne, komponentit, sekä näiden keskenäiset vaikutussuhteet. Löydökset viittaavat myös siihen, että resilinessin tärkeimpiä komponentteja ovat yhteistyö (collaboration), joustavuus (flexibility), sekä ketteryys (agility). Empirialuvussa tärkeimpänä havaintona ovat tuki teoriaosiossa muodostetulle resilienssin rakenteelle, sekä havainnot siitä, että haastatelluissa Suomalaisissa yrityksissä pandemia sai aikaan valmistelua, varmuusvarastojen lisäämistä, sekä lähempää kommunikointia kumppaneiden kanssa. Työssä havaitaan myös se, että yrityksen toimialalla on ilmeisesti merkittävä vaikutus sen toimitusketjun resilienssin tasoon, mutta tämä havainto on validiteetiltaan heikohko, johtuen pienestä otoskoosta. Työn lopussa haastatelluille yritykselle annetaan kohdennettuja ohjeita resilienssin suhteen, mutta ohjeet ovat käypiä myös muille samankaltaisessa tilassa oleville yrityksille. Lisäksi annetaan myös yleisemmellä tasolla menetelmiä, joilla toimitusketjun resilienssiä voidaan kehittää.

Avainsanat: Resilienssi, toimitusketju, toimitusketjun resilienssi, pandemia, COVID-19, toimitusketjun haavoittuvuus, disruption, toimitusketjun hallinta

PREFACE

In the beginning, around May and June of 2020, this thesis was planned to be part of larger research project about the supply chain resilience in Finland. Because of schedule difficulties, it was decided it would be the best to do the thesis separate from the original planned project. Regardless of that, the subject of the thesis was not directly changed after the changes in the plans.

This project lasted about 7 months, and it was both challenging and rewarding. Now, when the thesis is done, only the rewarding part of it stays with me, as the past challenges are not challenges in the present. Writing of this thesis has been invaluable learning experience, and at this point, I can be proud of finishing my thesis and studies.

I am grateful for the guidance and support of my supervisor, Prof. Jussi Heikkilä. His guidance pushed the project to the right direction and helped me to see and learn things from other perspectives, which was especially valuable in times of uncertainty and difficulties.

Tampere, 04.01.2021

Heikki Turja

CONTENTS

LIST OF ABBREVIATIONS

RM	*Risk management*
SC	*Supply chain*
SCRES	*Supply chain resilience*

1. INTRODUCTION

These days' supply chains (SC) are often very global, especially in manufacturing industries. Importing materials, parts, and other goods from all over the world is done on a large scale in many industries. The significant benefit of global sourcing is reductions in various costs, but this strategy for cost reduction may often also affect the supply chain in negative ways, as it creates complexity, and adds additional risks for disruptions (Gunasekaran et al. 2015). In the supply chain, if one player in the chain fails and must close business, at worst, other players in the SC need to close too, if they depend on the closing business (Jüttner et al. 2011). Even if the worst does not happen, it can easily cause disruptions in the chain. Companies have very little control over many causes of disruptions and risks, such as natural disasters or pandemic, and they also have limited control over other members of the supply chain (Jüttner et al. 2011).

Vulnerability to disruptions is increased by having too much dependency on one supplier, having long distances in the supply chain, having many country borders in the supply chain, and having many players in the supply chain (Colicchia et al. 2010). Even if the dependence for one source is not significant, when some global event creates global disruption, the continuity of manufacturing can be in danger. This happened to many businesses globally in the COVID-19 pandemic.

1.1 Background

Global pandemic such as COVID-19 can cause disruptions in all locations and industries, and it can happen in a short time. Thus, events like this are almost impossible to predict before they happen. This means it is not possible to be perfectly prepared for them, and the time to react can be very short. In addition, risk management (RM) in businesses is also said to be weakly focused on low-probability and high-consequence events, which pandemics are (Gunasekaran et al. 2015). When disruptions are already happening, it is too late to prepare for it. At that point it is needed to have already done preparations, and it is time to choose correct courses of actions. Having plans ready will help to choose the best possible actions in changing situations.

Being more dependent on far away sources and long supply chains can make businesses more vulnerable to disruptions. It can lead into problems with flow of goods and

loss of control and coordination on processes (Colicchia et al. 2010). During the COVID-19 crisis, many countries limited the movement of humans and goods, and set limitations on operating of businesses (Craighead et al. 2020). In addition, demand for certain items and parts did surge to exceptionally high levels (James Francis 2020; Litton et al. 2020). Similarly, the demand for some items dropped significantly (Habib et al. 2020). Many businesses had problems in their supply chain because of lockdowns, which disrupt either logistics, or production locally (Inoue and Todo 2020). As a result, globally important supplier countries like China, India, Indonesia, Taiwan, Vietnam, and Japan, have showed potential risks as a source of vulnerability in supply chains for manufacturers in Europe and Finland (Wouters et al. 2007; Andreff and Andreff 2009, European commission 2020). Global and national prioritizing of more important materials, like medical supplies and hospital equipment, can be one additional source of disruptions to other industries and supply chains (Dai et al. 2020). For society, it is even more important to make sure these critical supplies, which can save human lives, are distributed globally efficiently.

Some supply chains can recover more effectively from disruptions than others (Jüttner et al. 2011). That ability is the core of supply chain resilience (SCRES). According to Jüttner et al. (2011), supply chain resilience bases on the belief that it is not possible to avoid all disruptive events, and therefore there should be a focus on making the recovery from disruptions efficient. In this thesis, the main theme of is going to be supply chain resilience.

Another theme in this research will be crisis and disruption management of supply chains. This will give insight on how businesses can properly plan and prepare for crises and other unusual disrupting events. Because plans can never be perfect for unforeseen events, other equally important aspect is how can businesses spot early signs of problems, and in which ways they can react to the early signs. Last, the actions during already happening disruptions should be investigated in this topic.

1.2 Research goals and questions

The goal of this research is to find some insight on which things affect the supply chain resilience, and how it can be improved in Finnish manufacturing industry. The theoretical part of the thesis will build knowledge on SCRES, what it is, which are the building blocks of it, and how it can be improved. This knowledge will be used in the empirical part of the research, which will focus on the state and role of SCRES in Finnish manufacturing industry during the COVID-19 pandemic. Together with the theoretical material, this information makes it possible to analyse the situations of the SCRES in Finnish

manufacturing industry, and to find areas of improvements in it, and to give some directed recommendations or guidelines for improving SCRES in different situations. Based on these, the main goal of the research is decided to be…

> *…analysing the role of supply chain resilience in preparing and reacting to disruptions during the COVID-19 pandemic and finding ways to improve the resilience.*

For reaching this goal, the actions businesses have taken during the pandemic must be investigated. This can help to understand which actions, or the lack of actions, might have been helpful, and which ones might have been harmful for the business. For analysing the role of resilience in preparing and reacting for disruptions, the first research question of the thesis can be formed:

1. How can businesses, countries, industries, and societies be the best prepared for crises and disruptions, such as the global pandemic?

In pandemic, or any similar crisis, it is important for manufacturers, businesses, and entire countries to be flexible in their processes, so they can react to disruptions. Flexibility can be for example being able to change suppliers on brief notice or being able to build all new facilities to source critical equipment. This all can help not only businesses but also countries and individual people. However, flexibility and additional preparations can be costly, and there are other ways to improve preparedness. This aspect of increasing resilience and preparedness is in the next research question of the thesis:

2. In which ways can businesses prepare for disruptions the most efficiently, offering good resilience, without being too expensive to be financially suitable?

As mentioned earlier, depending heavily on global sources for supplies will increase vulnerability to global disruptions. Naturally, some industries are more dependent on global sourcing than others. For this reason, the role of resilience and improving is different depending on the business. This leads to the third research question:

3. What type of businesses are the most vulnerable to crises and disruptions, and have the biggest needs for resilience, plans and preparations?

Answering these three research questions will ideally result in reaching the stated goal of the research. The question 1 will help to understand the role of SCRES in preparing and reacting to disruptions, while the question 2 focuses more on the aspect of improving resilience. Answering the question 3 will give more specified knowledge about differences between industries, businesses, and individual needs for different aspects of SCRES.

1.3 Material and structure

The theoretical part of this research is based mostly on articles in scientific journals, but also on reliable available reports and statistics of relevant subjects. Focus with the articles is around supply chain resilience and flexibility, and disruption and risk management of supply chains.

The empirical part of the research is built around interviews of key personnel in Finnish manufacturing industry. This way the material which is collected will apply to this specific situation, and it can offer insight of the situation in individual businesses and their experiences, instead of statistics and situation on average. Specifics about interviews are discussed in later chapters. In this part of the research, also other new local statistics and research about effects of COVID-19 will be used, when available.

The rest of this thesis is structured as follows: in the chapter 2 the methodology of this thesis is introduced. The chapter 2.1 explains the methodology of the systematic literature review, while in the chapter 2.2 the methodology of empirical part of the research is told.

In the chapter 3, the theoretical background on resilience is constructed with systematic literature review. Supply chain resilience and the recognized elements of the supply chain resilience are introduced and defined in the chapters 3.1 and 3.2. In the chapter 3, the ways to build resilience and improve each element are explored, and the interconnections between the elements are found. In this chapter, also the role of each element is investigated. The main content of this chapter is information about each element, information about ways for increasing supply chain resilience, and exploring of the ways how the resilience affects the firm and its performance.

From the literature review, the interviews for the empirical part of the thesis are built, and the chapter 4 focuses around the interviews and their results. In this chapter, the results from interviews are explained, and the elements of supply chain resilience in each of the interviewed firm are rated with a rating system which is developed in the same chapter.

The discussion of the results is done in the chapter 5, where the material from the chapter 4 is analysed together with the support of the findings from the chapter 3. In the chapter 5.1, the research questions 1 and 2 are answered based on the findings from the interviews and the literature, while the chapter 5.2 answers for the third re-

search question. In the chapter 5.3, the reliability and validity of the research is evaluated.

In the chapter 6, the conclusions from the research are told. First, in the chapter 6.1, the main findings and contributions to the supply chain, and supply chain resilience literature are explained. The chapter 6.1 also compares the findings to the research questions of this thesis. In the chapter 6.2, general and targeted recommendations for the interviewed firms, and other firms in similar situation are presented. This chapter also includes recommended methods for developing supply chain resilience further in the interviewed firms. Suggestions for future research around this subject are identified, listed, and explained in the chapter 6.3. The future research suggestions are based on this thesis and identified gaps in the scientific literature on supply chain resilience.

2. RESEARCH METHODOLOGY

In this chapter, the research methodology of the thesis is introduced. First, the methodology of the literature review is explained. After that, the methodology for the empirical part of the thesis is briefly presented.

2.1 Systematic literature review

Systematic literature review is used in this thesis for systematically analysing scientific material. In this thesis, the methods are based on guidelines proposed by Seuring and Gold (2012) for doing literature review in the field of supply chain management. They offer four milestones as a structure for the method:

- Material collection
- Descriptive analysis
- Pattern of analytic categories
- Material evaluation and research quality

Material collection step includes defining methods for searching relevant scientific papers, deciding where to search and what types of papers to include (Seuring and Gold 2012). For this thesis, keyword search in *AndOr* search engine was used. AndOr searches material from the total of 409 different databases, including *ProQuest*, *Ebsco*, and *Web of Science*. Used keywords were *supply chain resilience*, *supply chain disruption*, s*upply chain risk management*, *supply chain vulnerability*, and *supply chain disruption management*. Articles related to this subject, which were written in English, and were published in peer reviewed scientific journals, were chosen. From the most relevant articles about supply chain resilience, also ”snowballing” back to its references was used to find more widely used articles about resilience. All articles in this step were picked by hand instead of using automation.

After this, 101 papers were collected, from which two rounds of refining took place. The first round was done to take out papers not directly related to resilience or key elements of resilience (e.g. agility, flexibility, vulnerability, collaboration). Also, articles which were in a narrow field of focus or relevance, that was not related to the themes of this thesis, were removed. This included for example papers about political disruptions

or disaster relief aid. This selection stage was done by reading titles, abstracts, introductions, conclusions, and looking over the content. 37 papers were remaining after this refining step. These papers are presented in the table in the appendix A.

In the second round of refining, the goal was to take out papers which were not closely enough related to supply chain resilience in the context of this thesis. These articles might have been focused on simulation of specific situation, or on broader system than supply chain, or about industry or location, which is too different from Finnish manufacturing industry. This step was done by reading each paper completely, or until it was clear that the paper was not relevant enough.

Based on Seuring and Gold (2012), descriptive analysis is collecting the distribution of papers in different journals, and the distribution over time period. This provides information about the collected literature sample.

For pattern of analytic categories step, following guidelines of Seuring and Gold (2012) for literature review, mixed method was used in this thesis. In the beginning of this step, categories for elements of resilience were set. These categories expanded during the review of the papers. Also new categories were added, and all categories were refined during the process.

As Seuring and Gold (2012) suggest, material evaluation and research quality step is for analysing the collected material. For this thesis, this step was done by reading through all the remaining papers and writing findings from those papers. Coding was used to collect information about what is found and mentioned in the papers. Coding was done on elements of resilience, meaning the things affecting resilience by increasing or decreasing it.

In the table 1 are collected information about how many papers in this literature review are from each scientific journal. In the table 2 is collected info about each paper in the literature review. The table 2 has columns for the authors of the paper including publishing year, brief description of the main focus, research method, and key findings of each paper. These papers in the systematic literature review are used in the chapter 3 to build theoretical framework about resilience and its elements.

Table 1. *List of journals and number of papers from them in this review*

Journal	***Number of papers***
International Journal of Production Research	*7*
Supply Chain Management: An International Journal	*2*
the International Journal of Logistics Research and Applications	*2*
International Journal of Physical Distribution & Logistics Management	*1*
International Journal of Disaster Resilience in the Built Environment	*1*
Business Strategy and the Environment	*1*
The International Journal of Logistics Management	*1*
Journal of Supply Chain Management	*1*
International Journal of Production Economics	*1*
Logistics Research	*1*
Computers & Industrial Engineering	*1*
the Production Planning & Control	*1*
the International Transactions in Operational Research	*1*
International Journal of Lean Six Sigma	*1*
IEEE Systems Journal	*1*

Table 2. *The papers in this literature review and their key info*

Authors	Main focus	Research method	Key information
Tukamuhabwa et al. (2015)	Definitions and strategies for improving resilience	Literature review, 91 papers	The most important elements are flexibility, redundancy, collaboration, and agility
Pereira et al. (2014)	Barriers and enablers to resilience	Literature review, 30 papers	The role of procurement with resilience. Inter- and intra-organisational issues impacting resilience identified
Wieland et al. (2013)	Improving resilience, effects on performance	Survey research, 1366 responds	Communicative and cooperative relationships have big role in resilience
Mandal et al. (2016)	Achieving resilience, the role of supply chain capabilities	Survey research, 339 responds	Relations between different supply chain capabilities identified. SCRES effects on SC performance
Piera et a. (2020)	SCRES elements, barriers and measurements	Literature review, 125 papers	Strategies to develop resilience and measure performance
Christopher and Peck (2004)	Creating resilient supply chain	Conceptual research	Identifying main elements of resilience and how to create resilience
Brandon-Jones et al. (2014)	Building resilience and robustness	Survey research, 265 responds, UK	Visibility and information sharing effects on resilience and robustness, role of SC complexity
Brusset and Teller (2017)	Supply chain capabilities, risk and resilience	Survey research, 171 responds	Lower-order capabilities and risk in achieving resilience
Gunasekaran et al. (2015)	Complexities, global sourcing strategies and resilience	Conceptual research	SCRES framework which shows complexities and strategies and their outcomes
Chowdgury and Quaddus (2017)	Multidimensional approach for building resilience	Mixed method	Elements of resilience and their roles and importance identified
Jain et al. (2017)	Supply chain resilience model development	Mixed method	Relations between resilience elements
Jüttner and Maklan (2011)	Supply chain resilience, vulnerability and risk	Mixed method	Effects of risk- and knowledge management on SCRES and vulnerability
Carvalho et al. (2012)	Agility and resilience with performance and competitiveness	Literature review	Conceptual framework for relationship between resilience and agility, and performance measures
Namdar et al. (2017)	Single and multi-sourcing strategies and resilience	Mathematical model	Collaboration and buyers warning capability are vital for SCRES
Soni et al. (2014)	Measuring resilience with deterministic modeling	Mixed method	Tool for measuring and analysing SCRES
Adobor (2018)	Building resilience, multi-level approach.	Conceptual research	Development of resilience from individual to firm to SC
Colicchia et al. (2010)	SCRES in global sourcing context	Conceptual research	Risk management methods for enhancing SCRES identified
Datta et al. (2007)	Improving resilience, operational perspective	Mixed method	Agent-based computational framework for analysing complex SC
Spiegler et al. (2012)	Conditions and controls for resilience.	Mathematical model	Performance measures and supply chain design, trade-offs and costs
Wang et al. (2016)	Multi-sourcing and rerouting for better resilience	Mathematical model	In multiple supplier chain, rerouting strategy increases resilience
Carvalho et al. (2011)	Divergencies and synergies with different SC strategies	Conceptual research	Explored divergencies and synergies with lean, agile, resilient and green SC strategies
Zhao et al. (2011)	Resilience in complex supply networks	Simulation	Effects of network design
Bhamra et al. (2011)	Concept of resilience and its effects in complex SC	Literature review	Resilience of different network topologies towards random and targeted disruptions to nodes in SC

2.2 Empirical research

The empirical part of this research was done by interviewing in Finnish manufacturing industry firms. For this thesis, as resources and time are limited, there is a need to focus on only a narrow field of industries to do the empirical research on. This way it is possible to get more profound information about the subject, instead of gaining swallow information on a wide range of industries and situations. The industries and specific firms were chosen with purposive sampling. The focus in this thesis is chosen to be on industries, which are reliant on import. Most of the chosen industries should represent the structure of Finnish overall manufacturing industry, instead of choosing businesses from less typical industries.

In Finland, the dependency on imported materials or products is high especially on electronics components, motor vehicles, medicine, textiles, chemicals, and machines and machine parts where over 70% of materials or components come from other countries (Ali-Yrkkö and Kuusi 2020). Also, Ali-Yrkkö and Kuusi (2020) found out in their report that in critical industries, such as grocery, agriculture, and energy maintenance, 20%, 14%, and 25% respectively, of the needed materials in the value chain come from foreign countries. Because of this, Finland is clearly relatively dependent on foreign countries in critical industries, and in industries which are important for the economy of Finland, the dependency is even greater.

In the year 2019, Finnish manufacturing industry structure measured by value of sold products was 43,7% metal industry, 20,9% chemical industry, and 18,1% forest industry (Official Statistics of Finland 2020). Metal industry can be further divided into metal and metal products with 15,9%, machinery and equipment with 21,0%, and transport equipment with 6,8%.

As it can be seen, metal, chemical, and forest industry are three of the biggest ones in Finland. From these, forest industry can be left out, as it is much less dependent on import than the others. Metal and chemical industries both are very significant industries in Finland, and especially chemical, and machinery and equipment industries heavily depend on importing material, parts, or products. From these, metal industry, and machinery and equipment industry firms are chosen to be interviewed for this thesis, based on availability and access for conducting the interviews. Another field of industry to be chosen should be one with high need of imported materials, so we can investigate the experiences, effects, and actions at management and planning in a global pandemic situation in highly vulnerable firms. In electrical components, the dependency on foreign countries is very high in Finland, with imported products being 88% of all

products (Ali-Yrkkö and Kuusi 2020). Therefore, firms with high need of electrical components are chosen to be interviewed for this thesis.

Four interviews were conducted as a part of this thesis in October and November 2020. Each interviewee was from a different company, and the interviews were separate events with no connection to each other. The people to be interviewed were chosen based on their knowledge about the subject: the person should have practical experience about supply chains, and good enough knowledge about production and management. These criteria ensure they can discuss the subject and answer the questions with enough reliability and certainty. Each person was contacted with the help of some personal contact, so there was some level of certainty about the required knowledge before the person was selected. Furthermore, the job title of the interviewee was considered when selecting who to interview.

All the interviews were done as remote virtual meetings with Microsoft Teams - application. In each meeting, there was only one interviewee and interviewer present. Before the interviews were arranged, one-hour time was requested to be reserved for the interviews. Interviews were recorded, and those recordings were used for making written notes after the interview. Those notes were then sent back to the interviewee in question to make sure everything is understood and interpreted correctly, and they were given a chance to give additional information and comments to their answers and the notes and correct any mistakes or misunderstandings. After receiving approval from the interviewee, the notes were used in this thesis.

The interview questions and the introduction can be found in the appendix B. This paper was sent as the same to all interviewees before the interviews took place, and no changes to it were made during any step of the process after this. Semi-structured interview method was used in this research. The question-set was built and sent to each interviewee before interviews, but in the actual meetings, conversations could flow freely, without strict control on staying in the subject or answering exactly the question in hand. When needed, additional questions and clarifications were asked.

There were 14 questions in each interview. The questions were categorised in the same three categories as presented in this thesis: working together; speed and adaptability; preparedness and structural strengths. Each of the elements of supply chain resilience, which were used in this thesis, was included in one or more questions, either directly or indirectly. However, this does not directly make it possible to make conclusions about each individual element, as the sample size is small, and the effects of each individual element are impossible to separate from other influencing factors.

After the interviews, the answers were analysed based on the theoretical framework built in the chapter 3. From the analysis and summary, the reliability of the answers and results were evaluated, and finally, they were used together with the framework to draw conclusions about the subject.

The analysis of the answers was based on deductive analysis method. As the interview questions were already set in the same categories which were built in the theoretical part of the thesis, they are used for analysing and categorising the answers. Each element in each category is evaluated for each of the firms. The definition of elements in chapter 3.2, and the analysis of elements and their connections in the chapter 3.4 were both used in analysing of the answers from the interviews.

From the interview, analysing of any element was not limited to only specific answers, but instead all answers were evaluated, and all the relevant information for any element was picked. Direct answers were the primary source for analysis, but also indirect answers, unsure answers, and questions without answers were used as a weak support for other findings when feasible. The voice and way the interviewee expressed him/herself was not considered when analysing the answers, and nonverbal communication was not analysed. It is important to mention that this kind of qualitative research with a small sample size has its own challenges in analysing and grouping of the material, and there is some element of subjectivity in the process.

Below in the table 3 is collected basic information about each of the interview. Companies are represented by letters, so they can stay anonymous. The field of industry of each company is told only vaguely, also for the anonymity. In the last column, the job title or area of responsibility of interviewee is told.

Table 3. *List of the interviewed firms.*

Firm	*Industry field*	*Interviewee's job title*
A	*Industrial, Electric & Electronic Machinery*	*Operations, production, purchases, and logistics*
B	*Industrial, Electric & Electronic Machinery*	*Production and purchase manager*
C	*Industrial, Electric & Electronic Machinery*	*Head of delivery process and planning*
D	*Metals & Metal Products*	*Logistics manager, responsible for production planning and logistics operations*

From the table 3 we can notice that all the interviewees were in position where they have an expert knowledge of especially logistics, but also overall situation about pro-

duction and purchases. Three of the firms are categorised in the same industrial field, but their business is highly different from each other.

The firm A is an Industrial, Electronic & Electronic Machinery firm, with a turnover being below 500 million EUR, and it employs less than 2000 people globally. The firm has its headquarters in Finland, and it serves customers all over the world, having organised business units for the regions of Americas, Europe, Asia-Pacific, Middle East, Africa, and China. Their markets are very diversified, and none of the areas are disproportionately hugely more important than others. They have production facilities in America, Europe, and China, and hundreds of suppliers around the world.

The firm B is an Industrial, Electronic & Electronic Machinery firm, with a turnover being below 1 billion EUR, and it employs less than 5000 people globally. The firm has its headquarters in Finland, and it serves customers worldwide, exporting to over 100 countries, their primary market being in Europe. Their manufacturing is done in Finland, but they have facilities, especially for distribution and services, around the world in Europe, Americas, China, and other parts of Asia. They have extensive supply network around the world.

The firm C is an Industrial, Electronic & Electronic Machinery firm, with a turnover being over 10 billion EUR, and it employs above 50000 people globally. The firm has its headquarters in Finland, and it serves customers all over the world. Their business operates in Europe, Middle East, Africa, Asia-Pacific (including China), and North America. Their production and R&D are done in multiple facilities in Europe, Asia, and North America. They have thousands of suppliers around the world.

The firm D operates in Metals & Metal Products industry. It has a turnover above 5 billion EUR, and it employs above 10000 people globally. The firm D does not have its headquarters in Finland, but in this thesis, the interview was mostly focused on the Finland's branch of their business, and unless specifically mentioned, all material about firm D is about that part of their organisation. For this part of their organisation, their sales are focused on Europe, with less than 10% of sales coming from outside of Europe. They have production sites in Finland and Sweden, and customers in all over the Europe, and parts of Asia. The whole organisation has thousands of suppliers, mainly for raw materials, in tens of countries, mostly in Europe and United States. The part of their operation which is the focus on this thesis, however, has very few suppliers, and their supply chain is very vertically integrated within the organisation. For this reason, their supply chain is very concentrated in small geographical area in Finland and Sweden.

Before the interviews it is assumed that global firms with more sales and suppliers around the world are more vulnerable to SC disruptions, and therefore would require higher SCRES for being more competitive and efficient. Large firms also more likely have more available resources, while smaller firms maybe cannot afford to invest in SCRES. In addition, large firms can benefit from the economies of scale, and the same investment in SCRES can benefit a much larger supply network.

About the industrial field from the selected firms, the metal industry might have less resilient SC. This might be true for all industries with heavy materials where the cost of shipping over long distance is not economical compared to more local options. For the firms A, B, and C, it is assumed that they are so heavily dependent on imported materials that they require higher SCRES for being competitive and functional. This assumption is based on the earlier mentioned statistics of dependency on imported materials In Finland.

3. THEORETICAL BACKGROUND

In this chapter, the theoretical material from scientific papers about supply chain resilience is analysed. First the chapter starts by introducing the definition of supply chain resilience in chapter 3.1. After that, in chapter 3.2 the building elements of supply chain resilience are introduced, which in chapter 3.3 are grouped in systematic and logical way, best suitable for this thesis. In chapter 3.4 the ways to build and increase resilience are explored. Chapter 3.5 briefly goes into the effects of resilience on performance. Similarly, in chapter 3.6 ways to measure resilience are explained briefly.

3.1 The definition of supply chain resilience

In the literature, supply chain resilience is defined in various different ways, but the general idea is always the same: it is the ability to respond quickly to unexpected disruptions, and return operations back to normal performance level, or to an even better level. Many, but not all, definitions also include the readiness to disruptive event in the definition of resilience (Tukamuhabwa et al. 2015). For this thesis, also readiness is included in the definition. Reasoning for this is that for managerial purposes, it is more valuable to also investigate the aspect of preparing for disruption, instead of only looking how to react to it. In addition, good preparation to disruption also affects the recovery speed and efficiency, and there is no need in this context to draw a line between preparation and other parts of resilience.

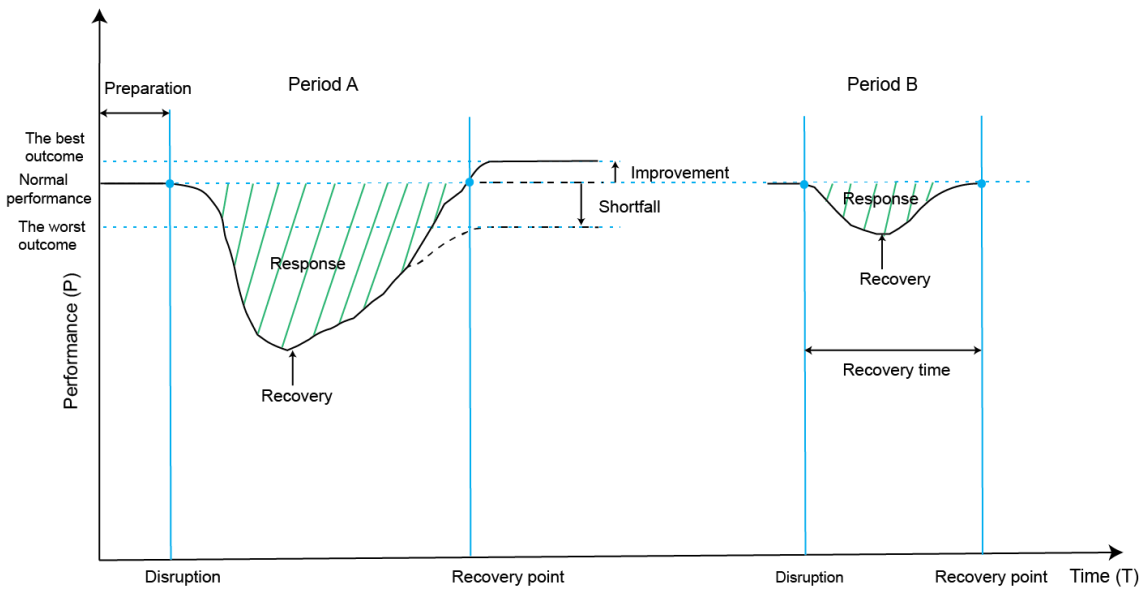
Tukamuhabwa et al. (2015) go through many important aspects and definitions of resilience in their paper, which reviews 91 scientific papers around the subject. Based on those, they define supply chain resilience as:

"*The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption.*"

This definition has four aspects in it. In this order, first, there is preparation to a crisis or a disruption. Then there is the response to that event, what reactions it causes. This is followed by a recovery from the event. And last, there is the growth and learning phase after the event. (Tukamuhabwa et al. 2015) This all together means that resilience is in all stages of disruption: being prepared, reaction to it, returning to normal, and improv-

ing because of it. This is visualised in the picture 1 below, which shows the performance over time during a disruption.

In the picture 1 in the time period A, a disruption occurs, which makes the firm's performance to go much lower. Before the disturbance there is a preparation time, which does not influence the performance. At the point of recovery, the performance climbs up again. A recovery point is the point when the performance is back to the same level as before the disruption. As the performance gets to previous levels, it can settle to three levels presented in the picture. First, it can settle to the level of "the worst outcome", where there is a shortfall between normal performance and the performance between the disturbance. The performance can also return to the same level as it was before the disturbance. Last, the performance can return to a higher level that it was before the disturbance, and thus there is improvement. This is the effect of learning in resilience and returning to a better state after disruption. In the picture, period B presents another similar disruption in the same firm after disruption A. Now the effects of disruption are much smaller, because the firm has already experienced that before, and has learned correct courses of action, and is therefore more resilient to this disruption, than it was at the period A.



Picture 1. *Visualisation of the definition of supply chain resilience. Adapted from Tukamuhabwa et al. (2015).*

It is good to note that supply chain resilience is connected to other aspects of supply chain, even on the company's operational level, not only in theory. Bhamra et al. (2011) for example, explain that resilience is connected to vulnerability and adaptive capabilities. They say that resilience is a component of a system's capacity of response. Supply chain resilience is also connected to supply chain risk management and disruption

management. This can be easily understood, as supply chain risk management has the goal of reducing supply chain vulnerability and uncertainties, and supply chain resilience is about minimising the effects of disruptions (Ho et al. 2015). Disruption management on the other hand is even closer to the area of resilience, as it classically includes risk identification, risk analysis, and risk response (Zhang et al. 2018). Disruption management can be seen as being part of SCRES.

In the literature it is agreed that resilience has “lower-order” capabilities, or elements. These are the capabilities, or enablers, which affect and build the resilience. In some papers it is said that resilience is made of few key elements, and secondary elements affecting these (Jüttner et al. 2011; Wieland et al. 2013; Chowdhury and Mohammead 2017; Shashi et al. 2020). Other papers take all these elements as one group, which affect resilience directly or indirectly (Roberta Pereira et al. 2014; Tukamuhabwa et al. 2015; Jain et al. 2017). In the literature review, one goal was to find out which elements are mentioned to affect resilience in which papers. The results of these findings in the literature review are listed in the appendix C.

Some papers were more focused on limited aspects of resilience, for example Wang et al. (2016) focus mostly on agility and rerouting as a tool to achieve resilience and did not go into detail of what resilience itself is. Kang Zhao et al. (2011) used resilience mostly as a measurement tool to compare supply network designs. Bhamra et al. (2011) looked resilience instead only in the supply chain. From the results, we can clearly see how flexibility, collaboration, information sharing, and risk management are all mentioned in most of the papers, but elements, such as coordination and control, financial strength, and sustainability, are much less frequently mentioned. This can show that the more frequently mentioned elements in the literature are the most important aspects of SCRES. But on the other hand, those elements might be more visible and easily detectable elements. For this reason, this is not enough evidence to make reliable conclusions about the importance of each element of SCRES.

3.2 Elements of supply chain resilience

Below are collected the definitions of the common elements mentioned in the SCRES literature. These definitions are similar in all literature around this subject, but minor differences can be noticed in some terms.

Flexibility is the ability to adapt to changes in environment and stakeholders with ease. This can be for example ability to postpone orders and operations, order fulfil-

ment flexibility, flexible transportation, flexible supply base, flexible labour arrangement, and so on. (Roberta Pereira et al. 2014; Tukamuhabwa et al. 2015)

Jüttner et al. (2011) describes flexibility as the number of available options, and the difference between these options, which can be used as an alternative if the market situation changes. Mandal et al. (2016) tells that flexibility is the ability to stand disruptions without disturbance, by using alternate courses of action, planning, etc. to minimize the impact of disruptions on operations.

Redundancy is the strategy of having spare capacity and inventory (Tukamuhabwa et al. 2015). Naturally, if there is redundancy, it creates safe net if problems arise. Being not too dependent on one supplier, for example by having other supplier options, decreases vulnerability to problems with that single supplier.

According to Tukamuhabwa et al. (2015) **Visibility** is the ability to see through entire supply chain and its status, which allows to detect incoming disruptions better, and allows better detection of vulnerabilities. It also helps with the correct response, instead of over- or under-reacting to disruptions. Jüttner et al. (2011) describe visibility as the level of which supply chain actors can have access to correct and timely information about operations. In the paper by Mandal et al. (2016), visibility is described as correct information about identity, location and status of all entities in supply chain, in the right time.

Supply chain agility is the ability to respond rapidly to changes in supply or demand (Roberta Pereira et al. 2014; Tukamuhabwa et al. 2015). Therefore, it is a critical component in supply chain resilience, as it can reduce reaction time to disruptions.

Collaboration is about working efficiently with other entities for mutual benefit (Tukamuhabwa et al. 2015). This can be done in areas such as information exchange, forecasting, postponement, and risk sharing.

Mandal et al. (2016) say collaboration is a partnership process, working together sharing resources and achieve common goals. One member in supply chain does not always have all the required resources, or it is not feasible to create or achieve these resources alone. The flow of real-time information can be as important as the flow of goods (Brusset and Teller 2017).

Integration is defined by Brusset and Teller (2017) as the degree to which members of supply chain work together and manage their intra- and inter-organisation processes.

Information sharing within supply chain means exchanging of information between the members of supply chain (Roberta Pereira et al. 2014). The information can be for

example about disruptions, risks, events, or more usual updates about day-to-day operation.

According to Roberta Pereira et al. (2014), **financial strength** as a resilience enabler means the financial situation and profitability of supplier. This is said to be important, as weak financial strength can be risky for business continuity in case of troubles and disruptions.

Coordination and control in supply chain means having plans and strategies, and the ability to act according to those plans (Tukamuhabwa et al. 2015). These plans can be within the organisation, or within the supply chain.

Trust between members of the supply chain is also agreed to be one enabler of SCRES (Tukamuhabwa et al. 2015; Jain et al. 2017). Trust required for a high level of cooperation and sensitive information sharing, and it is required for long-term cooperative relationships (Jain et al. 2017).

Supply chain design according to Tukamuhabwa et al. (2015) is about the balance of different aspects of supply chain, for example redundancy, efficiency, vulnerabilities, and the construction of the supply chain with different focuses.

Risk management is in the supply chain context about recognizing risks and using them as a part of the decision-making process (Christopher and Peck 2004). Risk management can be extended to be organisation-wide culture (Tukamuhabwa et al. 2015).

Company's knowledge and knowledge management is about the capabilities created by information within the company and its workers. In addition, it is developing, storing, and sharing of that knowledge, and the ability to learn and educate. (Roberta Pereira et al. 2014; Tukamuhabwa et al. 2015)

Velocity means the pace of which flexible adaptations can take place for recovering from disruptive events (Jüttner et al. 2011; Tukamuhabwa et al. 2015). It is also defined as a speed of which products and materials are delivered from the first-tier supplier to the end customer, through the supply chain, when order is made (Christopher and Peck 2004). The latter definition would mean velocity is rather a component of agility than directly a separate component of resilience. Carvalho et al. (2012) notes this difference, and claims that in resilient approach, velocity means pace of adaptations, whereas in agile approach, it means the speed of products moving through the supply chain.

Roberta Pereira et al. (2014) describes **Complexity** as the level of different players and flows of goods and information in the network. They recognize how long supply chains can create problems, as the complexity increases uncertainty and risks for problems, for example, because of political instability in various regions.

Sustainability is described by Jain et al. (2017) as using of resources without compromising the needs of future generations**.** Tukamuhabwa et al. (2015) recognize sustainability as economic, social, and environmental requirements for supply chain, which affects reputation and political risk.

3.3 Grouping of elements

In some papers SCRES is told to be made of just a few key components, which have their own sub-components. Other papers do not have this kind of grouping at all, but list all the elements with the similar importance together. In this section, grouping of components of SCRES in the literature is investigated more closely.

Piera et al. (2020) splits SCRES into three parts: anticipation, resistance, and recovery and response, and each of these groups has many elements in them. This categorisation is in chronological order from the perspective of disruption, which goes along with the definitions of resilience in scientific journals. Very similar structure is presented by Chowdhury and Mohammead (2017), who present that the categories are proactive capabilities, reactive capabilities, and SC design quality, which all have 12 sub-dimensions in them.

Wieland et al. (2013) explain that resilience is made of only robustness and agility. Robustness comes from anticipation and preparedness, and agility comes from visibility and speed. They also recognize how other capabilities affect these major elements. For example, communication affects both agility and robustness, and cooperation affects only agility (Wieland et al. 2013).

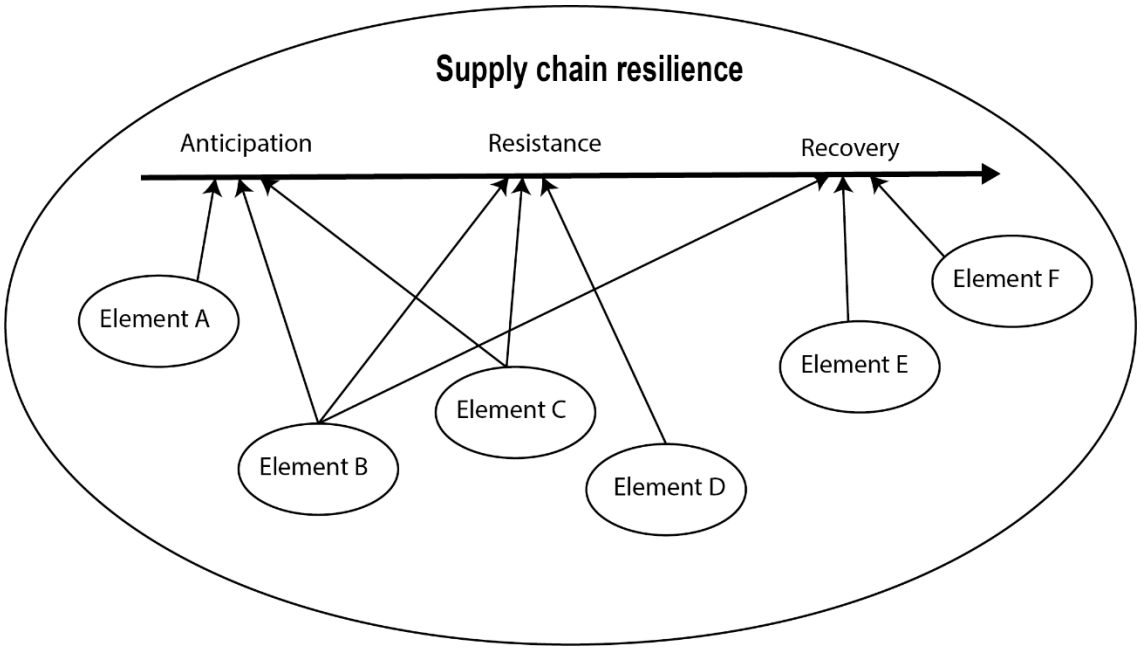
Carvalho et al. (2011) claim that resilience is made of redundancy and flexibility, but other conditions are also recognized, such as agility, collaboration, and SC design. In their paper, they also say how agility and resilience are two different things, and neither one is part of the other. This is supported also by Carvalho et al. (2012), but on the other hand, Wieland et al. (2013) and Tukamuhabwa et al. (2015) for example claim the opposite, saying agility is one component of SCRES.

Both Jüttner et al. (2011) and Mandal et al. (2016) argue that resilience is made of collaboration, flexibility, velocity, and visibility. However, they both recognize that also other elements affect these elements. Only slightly different view is offered by Tukamu-

habwa et al. (2015), who tell that the strategies for supply chain resilience can be summarised with four key groups: flexibility, redundancy, supply chain collaboration, and supply chain agility. They also recognize other elements too and only claim these are the groups of which include other lower-order elements in them. Christopher and Peck (2004) state that resilience is made of collaboration, agility, SC re-engineering, and SC risk management culture. This way of grouping differs slightly from the others, as it is the only one focusing directly on RM and re-engineering.

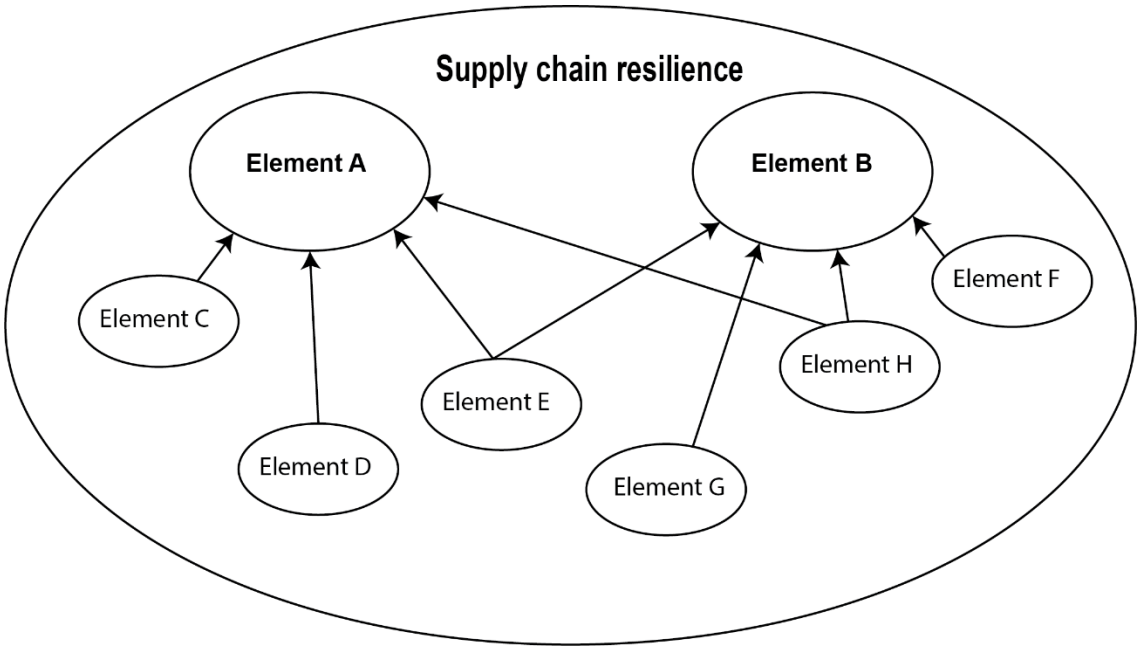
The same elements, which were recognized before as the most mentioned in the literature, are also here as the most common groups or key components of SCRES. Especially collaboration, some form of flexibility, and some form of speed of changes, are all clearly often mentioned as important components of resilience. This finding is important for understanding how SCRES is built, and which aspects of it are the most critical.

From these, it is possible to build a way to group and categorize the elements in a way that fits the best for this thesis. The first option to group the elements is to use a chronological approach. The elements would be grouped based on their point of relevance in the timeline of disruption. This way the groups would be split into anticipation and preparation group, resistance and action group, and finally recovery and learning group. The problem with this way of grouping is that many capabilities would fall into multiple groups. Collaboration, for example, could go into each of these groups. Flexibility and agility could be also argued to belong into each group. Therefore, for this thesis, this way of grouping would not be a practical choice, even if it would be a logical option for other reasons. This way of grouping is visualised below in the picture 2.



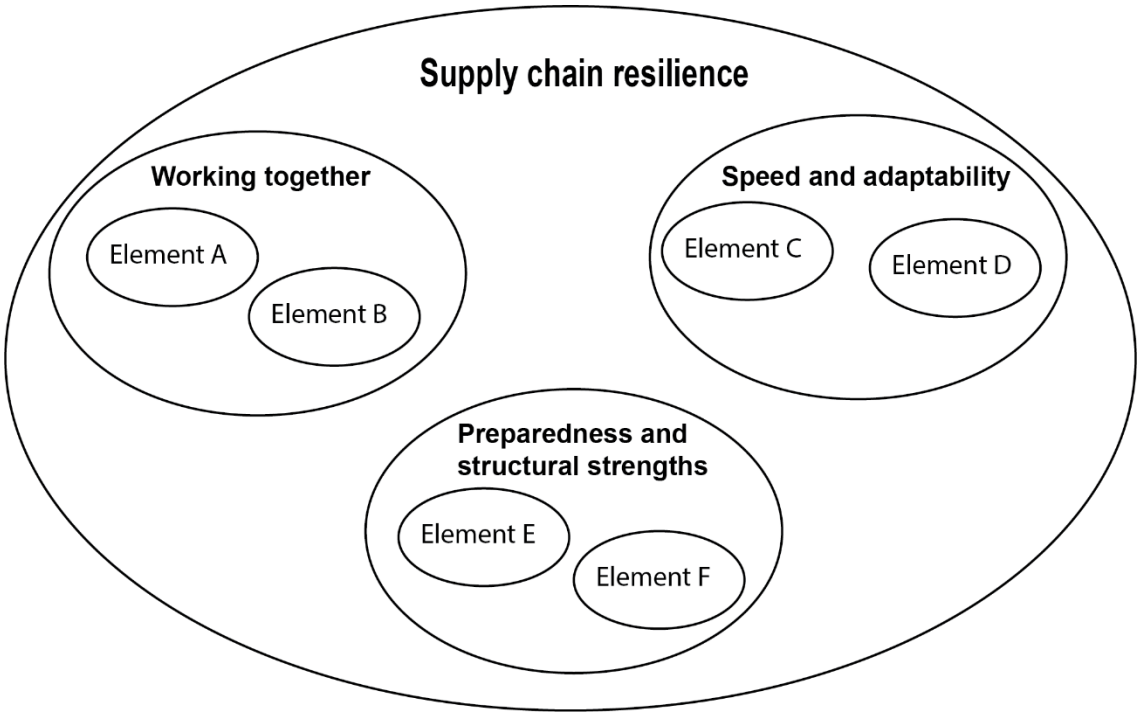
Picture 2. *Grouping of elements based on chronological approach.*

Another option would be to group the elements based on their role in resilience. For this, SCRES should be split into key parts. One way to do it would be the same as done by Wieland et al. (2013), which is to use robustness and agility. Another option would be to use the same approach as Carvalho et al. (2011) by using redundancy and flexibility. However, with these options there are few weaknesses. Carvalho et al. (2011) do not recognize agility as part of the SCRES, and if in this thesis their way of grouping is adopted, then also the same position should be taken regarding agility. Also, neither of these options give much importance to communication and working together. In also this option, it would lead to having some elements in multiple groups at the same time. For developing the framework and understanding what SCRES is, this approach would be without problems. In this thesis, as the goal is to have good contact also in practical context with easy usability and analysation, it is better to avoid grouping the elements in this way. The goal is to use grouping at this point for simplifying the structure of SCRES and its elements, and for this reason, this option for grouping is not desirable. This way of grouping is visualised below in the picture 3.



Picture 3. *Grouping of elements based on key elements as main groups.*

The third option would be to find out the most important larger categories to which the elements fall into. This could be like the way Jüttner et al. (2011) and Tukamuhabwa et al. (2015) group the elements. However, as now the goal is not to find the most important elements, but the most important groups, those are not usable directly as presented in their papers. From the material it can be seen that collaboration and other ways of working together is one very important group and should be taken as one also in this thesis. In this thesis, this group is defined as **working together**. Another group which is recognized by almost all the papers is some form of speed and adaptability. There are differences in the focuses in the literature, as some focus on agility, some on flexibility or velocity. The basic idea is still similar enough to be grouped under one category, which is here called **speed and adaptability**. For the next and final group, the focus should be on anticipation, preparedness, and strengths before disruption occurs. The reasoning for this is that preparedness is in many papers regarded as an important category under resilience, and in this thesis, it has been included in the definition of SCRES. Because some elements listed before are not only related to conscious preparation for disruption, but more about the strengths already present, the last group should be called **preparedness and structural strengths**. This way of grouping is visualised below in the picture 4.



***Picture 4**. Grouping of elements based on higher categories.*

The third way of categorising the elements under these three groups provides the needed simplicity and has strong reasoning, and it fits the best for the purposes of this thesis. For that reason, it will be used as a way to group elements in this thesis.

3.4 Building supply chain resilience

One finding in the literature presented by Mandal et al. (2016), also supported by Bhamra et al. (2011) is that SC capabilities are inter-related. This means they are connected to each other, and they affect each other, besides affecting supply chain resilience. This phenomenon is explored more in detail in this chapter. In this chapter, also the goal is to find out strategies to build each element and resilience and to find out information about the effects and roles of each element.

The elements of SCRES are categorized in three groups, which were formed in the previous chapter. It is worth to note that not all the elements are strictly only in one group but can be very closely connected to another group as well.

3.4.1 Working together

Visibility

According to Jüttner et al. (2011), visibility in supply chain improves decision making in businesses, as it helps to see problems early and e.g. to see the need for choosing

other suppliers or alternative strategies and actions. In disruption situation, visibility therefore helps to react quickly and mitigate the negative effects of events.

Visibility is said to be a critical part of working together in a supply chain, and it is agreed that open information sharing, collaboration, trust, and connectivity between the members of the supply chain will result in better visibility (Christopher and Peck 2004; Brandon-Jones et al. 2014; Soni et al. 2014; Jain et al. 2017). If members of the supply chain are not working together and sharing information, it is a natural outcome that the visibility in the SC is low.

In addition, Jüttner et al. (2011) argue that supply chain risk effect and knowledge management enhance resilience by improving visibility. Also, Mandal et al. (2016) says that integrated logistics capabilities, which have the goal of unification of logistics capabilities in the supply chain, affect positively SC visibility. This means that with greater level of unification within the firm and within the supply chain, the better visibility it gives across the supply chain. The reason for this is that with unification of capabilities and methods of doing things, more relevant information can be communicated about the critical aspects in the supply chain efficiently (Mandal et al. 2016).

Visibility is required for getting the correct information fast, which can be used with flexibility to take faster actions. For increasing visibility, communication and working together within the supply chain are clearly the most important aspects.

Collaboration

Supply chain is an entire network, and disturbances might affect all members in it. In their paper, Christopher and Peck (2004) say it is beneficial for the chain to share information and collaborate as that reduces uncertainty and risks and increases visibility and supply chain knowledge. Collaboration helps to create fast responses and getting the right information in right time at the supply chain level. This creates for the supply network the ability to respond more rapidly to disruptions or crisis together. Also, close collaboration enables just-in-time strategies more because it makes working with low margins of error easier, and it also can help with cost savings, as working together can be more efficient and fluent (Christopher and Peck 2004; Jain et al. 2017). According to Jüttner and Maklan (2011), collaboration also enhances SCRES, because it can enable members of the supply chain to support each other when disruptive event occurs. Related to this, Soni et al. (2014) and Mandal et al. (2016) accept that visibility is critical for increased collaboration.

According to Roberta Pereira et al. (2014), collaboration between supplier and buyer may help lower supply chain risks significantly, especially with global sourcing with in-

creased complexity. Lack of confidence results in bad visibility and collaboration, which decreases resilience. Soni et al. (2014) and Jain et al. (2017) also point out the importance of trust as an element which increases collaboration. Also, Jüttner et al. (2011) investigate supply chain risks and tell how risk and knowledge management enhances resilience by increasing collaboration. They also say how collaboration can lead to risk sharing, which can be beneficial for all parties. Mandal et al. (2016) claim that integrated logistics capabilities also affect collaboration positively. This is not a surprising finding, as working together is required for unification of capabilities, and unification of capabilities can lead to working together more closely.

In their paper, Jüttner et al. (2011) talk about effects of collaboration, and tell that collaboration smooths the effects on the supply chain in crisis. Collaboration helps to maintain the supply when problems occur, for example by arranging of priority from the supplier, making an agreement for value-based pricing, or by making agreements for facing extreme peaks in price fluctuation together and sharing its effects with multiple players in the supply chain. (Jüttner et al. 2011)

Gunasekaran et al. (2015) tell how transactional relationship, meaning low levels of closer collaboration, is better for common and simple supplies with low value and with many available suppliers. They tell that for complex and specified supplies, strategic partnership and closer collaboration is preferred form relationship. This suggests that high collaboration is not worth pursuing for with all suppliers. Collaboration simply does not bring enough benefits with suppliers of simple and non-critical items. Collaboration itself requires some number of resources, especially time and effort, and it is not rational to spend those resources if there is little or no gain from it. With critical suppliers, or suppliers of complex or important items or materials, collaboration is clearly beneficial and very important for SCRES.

Integration

Integration is element which have got very little attention in the supply chain resilience literature. In some papers it is mentioned, but even in those, it is not one of the primary focuses of the paper.

Wieland et al. (2013) tell that integration does not affect agility or robustness, and therefore not resilience. They claim this because in their paper, SCRES is defined to be made of only agility and robustness, and therefore all which are not directly affecting those, are not part of the resilience. Wieland et al. (2013) suggest that the positive effect of integration regarding resilience in the other literature might be because of improving communication and cooperation by integration. Other reason is told to be that

integration loses its benefits as it can decrease flexibility with tied-up resources, and for that reason they cannot see integration to be beneficial.

The difference between integration and collaboration is not apparently huge, as integration can be seen also as high level of collaboration, or one result of it. From the literature, the need for integration to reach supply chain resilience is not clear. Shashi et al. (2020) tell how the lack of integration can be harmful for resilience, as it can create delays, because information does not flow as efficiently. Also, Brusset and Teller (2017) point out the role of integration is important in using IT systems for more efficient collaboration and communication. This would suggest that integration is rather just a tool for better communication and collaboration, and not capability directly affecting SCRES on itself.

Information sharing

Information sharing is closely tied with collaboration and trust. Literature also supports this statement, as Soni et al. (2014) say that better trust, collaboration, agility and visibility leads to higher levels of information sharing. But on the other hand, Jain et al. (2017) tell it is the other way, that information sharing leads to trust and visibility. These findings are possibly both true, as they might be all reinforcing activities with each other. These points of views on information sharing are from the supply chain's perspective. Information sharing can be also investigated from the company's perspective at the company's level. This aspect is discussed by Roberta Pereira et al. (2014), who tell information sharing can be increased by creating a culture, where workers are encouraged to share their knowledge, and by adapting the use of technology to store and share knowledge.

Soni et al. (2014) explain how sharing of information related to demand and forecasts can be beneficial and decrease vulnerability within the supply chain, as it minimizes the consequences of bullwhip effect, and other risks of non-accurate information related to demand. Collaboration and visibility are needed for this type of information sharing.

Roberta Pereira et al. (2014) go through sourcing strategies and different approaches to information sharing regarding these strategies. With single sourcing, there can be risks of high disruption impacts and opportunistic suppliers. Agile companies however often use small supplier base, but they prioritise into strong relationships and information sharing to mitigate these risks (Roberta Pereira et al. 2014). It can be concluded that information sharing in the supply chain can lower the risks in use of single sourcing.

Namdar et al. (2018) discuss warning capabilities in the supply chain and say that the buyer's warning capability is a vital element for SC resilience. This can be seen as one part of information sharing, because with the sharing of enough correct information in the right time, also potential problems and warnings are shared either directly or indirectly. In this form, information to be shared would be related to changes in the normal way of things, or to disruptions or problems which are detected. Soni et al. (2014) support this statement, as they say sharing of risk event-related information with others can help to manage risks.

Based on this, information sharing and relationships in the supply chain can be used as RM strategies, besides them being part of SCRES. It seems that information sharing can act as a bridge between collaboration and RM. Clearly information sharing is also connected to trust and visibility in the supply chain and between companies. There is some support also to the claim that information sharing is connected to agility, but with that statement, the findings from the literature are not completely clear.

Coordination and control

Coordination and control are mentioned in a handful of papers to be one building element of SCRES, but very rarely it is discussed more in detail (Spiegler et al. 2012; Roberta Pereira et al. 2014; Gunasekaran et al. 2015; Jain et al. 2017). Tukamuhabwa et al. (2015) mention that no single firm holds the control of the entire supply chain alone. For this reason, it is important to have coordination in the supply chain, and to have clear control together with other members in the chain. Shashi et al. (2020) go as far as saying how resilience is about controlling events. They also say how control is closely related to monitoring changes, which can itself be a method to build control.

Christopher and Peck (2004) categorise coordination and control under supply chain collaboration. This is in line with the other papers, as they also clearly see it as a part of working together in the supply chain. It seems that coordination and control are a part of collaboration, planning, and systematic way of working together with other players in the chain. Without coordination and control, collaboration and close relations alone might not be as helpful with the SCRES. It is also claimed by Priya Datta et al. (2007) that decentralised and well-coordinated supply network is good for supply chain resilience. This suggests that decentralisation, and probably also other complex strategies, can lose some of their benefits if they are without enough coordination and control.

From these, it can be summed up that coordination and control is related to keeping things efficient when working together. Monitoring and measuring are integral part of control, as monitoring allows to see what is happening, which is required for control.

Trust

The relation between trust and supply chain resilience is very little talked about in the literature. Often when trust is mentioned, it is mentioned as a part of effective communication, relationships, and working together in supply chain, but it is not investigated or discussed more on its own (Christopher and Peck 2004; Wieland et al. 2013; Roberta Pereira et al. 2014; Tukamuhabwa et al. 2015). This can be because collaboration and information sharing are seen to be more important elements related to resilience, and trust might be just a sub-element of those. Without enough trust, there cannot be sharing of sensitive information, or collaboration with very critical systems. It is similar to how trust between individual people affects social dynamics in complex ways, and it is much more important to recognise which effects the lack of trust has, than which benefits high levels of trust brings.

Building trust is not an immediate process. Soni et al. (2014) and Jain et al. (2017) tell how information sharing is one route to building trust. Soni et al. (2014) mention how collaboration, agility and visibility also increase trust.

For this thesis, it seems that trust is not very critical to be examined as a completely separate entity, but more together with collaboration and information sharing. This should be a rational choice for this purpose, as it is not possible to “build trust” on its own, because trust is rather a result from other activities. Trust acts more as a supporting element for other capabilities.

3.4.2 Speed and adaptability

Flexibility

Flexibility and the ability to adapt is one key aspect of resilience. According to Roberta Pereira et al. (2014), the lack of flexibility is one of the biggest barriers for achieving resilience. Priya Datta et al. (2007) tell how flexibility helps to adapt with unpredictable changes, such as changes between actual demand and forecasted demand. It is important for businesses to monitor the demand and know fast about changes, because all delays in getting the right information will also delay taking the correct courses of action regarding the new situation.

Creating flexibility can be done by multiple ways. In the literature, Jüttner et al. (2011) argue that increasing redundancy is one way to do it. They also say how RM in a form of sharing risks in the supply chain increases flexibility. Redundancy naturally creates backup options or resources, which can be used when things do not go as planned. Risk sharing on the other hand can be for example setting up logistics agreements,

where two or more partners are both responsible for logistics processes (Jüttner et al. 2011). This can also create flexibility, as there is more likely to be a backup solution more readily available and more resources in solving possible disturbances. Mandal et al. (2016) similarly say increasing collaboration and visibility between supply chain players results in more flexibility. This can also be explained with more options, resources, and information available in the supply chain, resulting in better flexibility, and better resilience.

Roberta Pereira et al. (2014) claim that increasing product flexibility is also said to be a route to flexibility, but it can also increase complexity, which decreases SCRES. This, however, is possible to mitigate by using modularity in the products (Roberta Pereira et al. 2014). Flexibility in products can be about the possibility of using different components in one place, or the possibility of using multiple suppliers for the same component, or the usage of alternative manufacturing processes or materials with the product or component. This can offer significant benefits, if there is a situation where the regular way of doing things has some disruptions and there is a need for an alternative. Roberta Pereira et al. (2014) also argue that relying on a single supplier can be risky regarding resilience, as that strategy makes vulnerable to disruptions, and can encourage opportunistic behaviour. This claim also shows how flexibility in supplier selection can be valuable.

Roberta Pereira et al. (2014) and Shashi et al. (2020) argue that flexible strategies are an effective way to reduce the effects of disruption and can help also with SC risk management. As an example of these strategies, they mention the usage of safety stock, flexible sourcing, and strategic souring. Wang et al. (2016) suggest that rerouting, which can be seen as one form of flexible strategy, creates resilience, and can make recovery from disruptions to be faster.

Jüttner et al. (2011) argue that flexibility helps to stay on cost and revenue targets, as it creates the possibility to shift to cost-effective sources, use multi sourcing, and reallocate capacity to optimise utilisation better. This is also supported by Roberta Pereira et al. (2014) as they also mention sourcing flexibility as a tool to achieve better cost-effectiveness and more bargaining power for negotiations. Saenz et al. (2018) claim that the more developed and focused SC is to cost reduction, the less flexible it is. The difference between these two views is that in flexible cost-reduction, the cost-effectiveness comes from having alternatives, which gives bargaining power and a wider range of flexible options. Cost-reduction focused strategy on the other hand can lead to, for example, big contracts with one single supplier, which on its own makes it more difficult to switch to any alternative supplier within a short time period.

Having more options available is clearly one key element in flexibility, as more options make it easier to make fast changes when necessary. Without those options, if problems arise, it would force the business to either not change anything, or to find new options, which would take time, which is one indicator of poor resilience.

Redundancy

The lack of redundancy is said to be possibly risky, as it makes vulnerable to disruptions when no other options are available (Roberta Pereira et al. 2014). Creating redundancy is on the surface very straightforward: create spare capacity, spare inventory, warehouses, or other spare options or resources. Some argue that redundancy is not separate resilience capability, but a route to flexibility (Jüttner et al. 2011; Soni et al. 2014). Therefore, based on that, it might not directly affect SCRES. As availability of options is also a key aspect of flexibility, it is easy to agree that redundancy is more directly related to flexibility than to resilience.

Building redundancy, however, is not always that simple, as increasing redundancy can at the same time increase costs and decrease efficiency. Christopher and Peck (2004) discuss this balance and conclude that surplus capacity offers more flexibility than surplus inventory and is therefore more valuable. This is since according to them, in many situations items in the inventory are already at that point committed to one or limited number of locations, paths, or products. For this reason, they offer only very limited flexibility in the form of redundancy, while still decreasing the efficiency. This argument of course depends on the industry type and the level of customisation needed for products and other items. If all the products or materials are very similar, with very little need for customisation and only small amount of speciality, surplus inventory is not as tied to one form of process or path, and therefore offers better flexibility from redundancy.

Roberta Pereira et al. (2014) have the same argument as Christopher and Peck (2004), saying that inventory redundancy can improve response times, but this typically increases inventory costs. They present two types of redundant inventory: safety stock for normal day-to-day fluctuations, and emergency stock for keeping effects of extreme disruptions low (Roberta Pereira et al. 2014). Safety stock is therefore tied with regular management of operations, whereas emergency stock is used more as a RM tool.

To conclude, redundancy in the production capacity offers higher impact on flexibility than redundancy in the inventory. In the inventory, safety stock is required for normal day-to-day operations, and cannot be counted as a tool for building resilience. Emergency stock, on the other hand, can offer some amounts of increased flexibility, and

therefore resilience, but at the cost of efficiency. For this reason, perhaps keeping emergency stock on highly critical items is valuable, especially if the supply of those items is vulnerable to disruptions, and their storage costs are not very high relative to other expenses, or expenses from a disruption.

Agility

On agility in the supply chain, there is no clear agreement in the literature. The focal point about agility is made by Roberta Pereira et al. (2014), who tell that agility can improve response times to supply disruptions. That is the core principle of agility in the supply chain. The way agility is related to other aspects of supply chain, however, is not completely clear.

Tukamuhabwa et al. (2015) argue that agility is made of visibility and velocity. Wieland et al. (2013) focus on the aspect of working together in agility, and say the main elements affecting agility are communication and cooperation. Roberta Pereira et al. (2014) mention that product flexibility has a positive effect to agility, which can be in practise for example the ability to use different components in the same place. These points are not contradicting each other, but they do not have the same focus. Maybe this is because in many papers' agility is a separate element from resilience, and not part of resilience directly (Carvalho et al. 2011). For that reason, some papers might ignore the role of agility with resilience, and never investigate how agility relates to the other elements and capabilities.

Wang et al. (2016) similarly approach the same subject from another direction and tell how the faster the rerouting in disruption situation is the better the resilience in the supply chain is. This suggests that rerouting is one agile tool in the supply chain. This would also mean that flexibility might be one enabler of agility, as with good flexibility there are possibilities for adaptations, which means better basis for making fast changes, which results in good agility.

Carvalho et al. (2011) go through agility related strategies for different situations. They suggest that lean strategy is the best when there is low uncertainty and variety, and predictable demand. But with high uncertainty and variety and unpredictability, a higher level of agility is needed. This means that agility gains more value when things are not clear and predictable. That is a logical result, because if things are very predictable, there is much less need to make fast changes and adaptions. But on the other hand, when focusing on disruptions, there is always some level of uncertainty and possibility for surprises. Disruptions from events are not planned everyday activity or variety in operations. High levels of agility can make it easier to react to those disruptions, but

high unpredictability will make agility more valuable capability even in times without disruptions. For this reason, it might be possible that firms operating in high unpredictability are naturally more capable of making fast changes, and therefore naturally more resilient to disruptions.

Velocity

According to Tukamuhabwa et al. (2015), velocity is the key capability in recovering from disruptions, as it is one factor which determines how fast adaptations take place. When disruption occurs, the speed of recovery is very critical, and is one of the most important aspects in the definition of supply chain resilience. Velocity is for this reason important for resilience.

Christopher and Peck (2004) and Carvalho et al. (2011) tell how velocity, meaning the speed of which material and goods move in the SC, can be improved by three strategies: streamlined processes, reducing in-bound lead-times, and reducing time in non-value adding processes. Streamlining means simplifying processes, for example reducing the number of stages using parallel processes instead of processing in series, and using digital information format, rather than physical paper. In-bound lead-times can be reduced by synchronized schedules and information sharing, but also supplier selection is in the key role (Christopher and Peck 2004). Non-value adding processes on the other hand are, according to Tukamuhabwa et al. (2015), often idle time spent in the inventory. If time spent in inventory is only for waiting, with no other purpose, it decreases velocity while giving no benefits.

Mandal et al. (2016) explore some relations between velocity and other SCRES capabilities and claim that supply chain visibility and collaboration are tied with velocity, meaning they enhance each other. Jüttner et al. (2011) argue that risk sharing, and risk management, and knowledge management all improve velocity. They argue as well that decentralized SC structure, instead of central hub structure, increases velocity.

Increasing velocity has also other benefits than increasing resilience. High velocity can mean increased cost-efficiency, as it can be done by cutting waste-time and optimisation. This way of improving velocity can be a good strategy, even if there is no specific need to increase SCRES.

3.4.3 Preparedness and structural strengths

Financial Strength

Financial strength is not much explored in the context of supply chain and resilience. Roberta Pereira et al. (2014) claim that suppliers' lack of good financial situation can be

risky for resilience, as it increases the risk of disruptions, e.g., forcing to close down the business, which can affect the entire supply chain. Even milder actions can lead to smaller disruptions in the chain.

According to Chowdhury and Mohammead (2017), company's own financial strength is a proactive resilience capability. It is easy to believe that good financial strength will increase a firm's ability to recover from disruptions. This, however, is true also in larger scale: good financial strength will aid in a wide variety of situations, and good financial strength itself is the goal of many other activities and strategies.

For this thesis, financial strength will not be looked as a separate key enabler of SCRES. Instead, it is more meaningful to see how the lack of financial strength can be harmful for SCRES, and how good financial strength might enable the investment in other elements of SCRES. Financial strength could be classified also as a sub-element of risk management based on these findings if the focus is on suppliers' or customers' financial strength and affects supplier selection.

Supply chain design

According to Chowdhury and Mohammead (2017), supply chain design includes three key parts: node density, complexity, and node criticality. Node density means how production, markets, and suppliers are concentrated or diversified in the SC. High density, meaning very concentrated nodes, reduces SCRES, because it increases the number of vulnerabilities in the same geographical locations (Chowdhury and Mohammead 2017). Complexity can be a result from the number of tiers in SC flows, number of players, use of multiple suppliers, or high number of customers. Complexity increases vulnerability, but also with the use of buffers and multi-sourcing, it can come together with improved resilience. Node criticality comes from having only few or no alternative suppliers, components, or transportation modes, or having critical distribution centre in the supply chain. Nodes with high criticality will make the supply chain more vulnerable as a whole, because of the impact of potential disruptions in those specific nodes. (Priya Datta et al. 2007; Chowdhury and Mohammead 2017)

The impact of critical nodes in the SC is also noted by other research papers. Kang Zhao et al. (2011) discovered in their paper that hub-based networks are resilient towards random disruptions, which can affect any part of the network, but more vulnerable to targeted disruptions, which focus on the main hubs, and therefore will have great impact on the supply chain.

According to Saenz et al. (2018), supply chains should be built with the aim of optimizing operational procedures, but also with the goal of achieving resilience. This ap-

proach aims to create balance between the efficiency and security, decreasing vulnerability, and in the long run, helps the businesses to continue operations even while facing disruptions. Saenz et al. (2018) present two fundamental characteristics of a supply chain which should be considered when designing supply chain: competitive priorities and scope. Competitive priority can be focused on cost-reduction or responsiveness. Focus on cost-reduction would direct the SC design into cost minimizing with more efficiency and less security, which creates a more rigid and less flexible supply chain with more vulnerability to unplanned changes (Saenz et al. 2018). Focus on responsiveness on the other hand would mean the SC design is planned to be agile and respond quickly, which usually makes it more able to adapt to changes and is therefore more resilient (Saenz et al. 2018).

Supply chain scope has also its effects on the SCRES. According to Saenz et al. (2018), local scope can offer better agreements and more seamless SC with local key suppliers and logistics service providers. Global scope can benefit from global strategies, such as outsourcing, and might enable better cost-minimising strategies, as there might be more supplier options available. This, however, increases SC complexity and vulnerability to changes in global networks and external threats, such as political, environmental, economic, or regulatory events and changes (Saenz et al. 2018).

Local supply chain is vulnerable to local events and is compact but usually more agile. It also gives the benefit of good position for collaboration and favourable agreements, which can result in even more agility and resilience. Global SC, on the other hand, gains benefit in cost-effectiveness, but also increases vulnerability to uncontrollable events, adding also new vulnerabilities, and has increased complexity. For this reason, the need for high resilience is more important for global supply chains than it is for local chains.

Risk management

As supply chain resilience is so closely related to vulnerability and risks, it is not a surprise that risk management plays a critical part in overall supply chain resilience. Christopher and Peck (2004) argue that risk management culture should be part of the decision making at every level of the organisation and supply chain. They say that for example in product design, it should be already investigated which aspects in the manufacturing and distribution might cause vulnerability to the SC. New decisions should be made with the consideration of supply chain risk profile.

Jüttner et al. (2011) argue that SC risk management, depending on the target, affects SCRES, SC vulnerability, or both. If the risk management is aimed at reducing effects

of risks, it increases resilience. But if it is aimed at reducing risk probability, it reduces vulnerability.

Jain et al. (2017) say that information sharing leads to lower uncertainty, which usually leads to lower risks. They also tell how visibility and collaboration leads to likelihood of risk and revenue sharing, which also can be seen as risk management strategy. This aspect considers internal risks within the supply chain, for example in disruption situation. Based on these, knowledge about what is happening is important for lowering certain risks, and the strategy of gaining that knowledge can therefore be seen as one form of risk management, which can increase supply chain resilience, but is focused of decreasing vulnerability.

According to Namdar et al. (2018), spot market options and backup suppliers can be used to manage risks. Another way for risk management told by Christopher and Peck (2004) is focusing on the risk profile of the supplier when doing supplier selection. This has the goal of identifying risks related to each supplier candidate, before committing to one supplier too much.

Company's knowledge

In their paper, Kang Zhao et al. (2011) tell that optimizing the supply chain is a hard task, because it requires knowledge and control of the entire network. For this reason, it is easy to see how a company's knowledge affects supply chain resilience, at least indirectly. Optimisation with wrong focus might be harmful for resilience, but also with too much focus on security and resilience, the negative impact on cost-efficiency might get too big.

The primary focus in the literature related to company's knowledge with SCRES is in working together and sharing the knowledge in the SC. This can be seen in findings of Tukamuhabwa et al. (2015), who point out that sharing of knowledge should be part of collaboration. Christopher and Peck (2004) also mention how collaboration increases supply chain knowledge. Similar findings are presented by Brandon-Jones et al. (2014), who tell how visibility encourages knowledge sharing between SC players.

Roberta Pereira et al. (2014) point out how learning from previous arduous experiences will build up the company's and supply chain's knowledge, and it can be used with strategies and decision making in the future. Gunasekaran et al. (2015) on the other hand, tell how knowledge management system should be an integral part of resilient supply chain. This finding is also supported by Tukamuhabwa et al. (2015).

Knowledge is a critical resource and working together is one way to increase it. Especially in SC context, where all the control is not with just one player, it is crucial to use

knowledge together for the benefit of the whole SC. Also, important aspect is learning from the past, as experiencing one type of disruption can make the company to plan strategies and preparations for similar disruptions in the future for minimising the vulnerability and improving the recovery capabilities.

Complexity

Long global supply chains may create vulnerabilities, as they are vulnerable to political and local risks of many regions. This will also increase risks of bankruptcies, breakdowns, and disruptions along the supply chain in various locations. One member of the chain can affect other members, and for this reason, increasing complexity of the supply chain can increase vulnerability and reduce agility for the whole chain. (Roberta Pereira et al. 2014)

According to Roberta Pereira et al. (2014) and Brandon-Jones et al. (2014), collaboration is required among supply chain members, and it can also create more visibility. This means that some negative effects of complexity on SCRES can be decreased by collaboration and visibility. Roberta Pereira et al. (2014) also mention that collaboration and visibility can increase risk sharing and communication benefits between supply chain members.

Research by Gunasekaran et al. (2015) suggests multiple ways to minimize complexities in supply chains: continuous monitoring, supply chain visibility, collaboration, focus on SC design, and focus on product design. They also say supplier selection is one key element in reducing SC complexity, and there should be a prime focus in supplier's quality, flexibility, dependability, responsiveness, cost, IT usage, and knowledge management.

Products themselves can be another source of complexity. Complexity in product design can come from many components, process stages, large amount of technologies used, technological difficulty level, the degree of specificity, criteria set on performance, development cost and time, competition, product cost, product life, and legislation related to the product (Barclay and Dann 2000). Some ways to reduce this product complexity are using modular design, mass customisation, and centralised inventory management (Roberta Pereira et al. 2014).

Complexity has proven to decrease performance of the supply chain (Bhamra et al. 2011, Gunasekaran et al. 2015). It is a major element of extra costs in the chain, and it affects resilience and flexibility negatively (Gunasekaran et al. 2015). For this reason, even without planning for SCRES, it should be a focus to decrease complexity, as this will improve efficiency. Complexity in the supply chain can easily increase without get-

ting much attention, because the effects of complexity are not always directly seen. Complexity can have indirect effects, and effects which can only be seen with delay. This, combined with the drive for cost-efficiency, can make it difficult to see and choose the best options for complexity, SCRES, and long-term profitability.

Sustainability

Sustainability in supply chain is talked in only two papers in this literature review (Soni et al. 2014; Jain et al. 2017). Jain et al. (2017) tell that better understanding which actions improve sustainability in the supply chain will help to make better quality decisions and decrease risks in the whole supply network and in single organisation. They claim that from other supply chain capabilities, RM culture, technological capability, and SC agility leads to better sustainability. Soni et al. (2014) have similar results in their paper: adaptive capability, SC structure, risk and revenue sharing, trust, visibility, and RM culture all contribute to creating sustainability in the supply chain.

Sustainability is clearly under-explored capability of supply chain resilience. Sustainability seems to be important as a guidance tool and is clearly related to RM and relations within the supply chain.

3.4.4 Other strategies

In this section we look on resilience building on general level, not only from the perspective of one element. One distinct look into resilience is offered by Adobor (2019), who investigates resilience on multiple levels: employee, firm, and supply chain level. He argues that employee resilience leads into organisational resilience, which leads into supply chain resilience. These levels also have their own sub-elements, which for SCRES are inter-partner learning, supply chain risk management culture, and inter-firm trust and collaboration.

Brusset and Teller (2017) argue that supply chain resilience is an operational capability, not dynamic capability. Dynamic capabilities are learned from experience and will give a competitive advantage. Operational capabilities are required for normal operation, and they form the ability to execute and do tasks. This would mean that SCRES is needed for regular business operations, and lack of it is a big vulnerability for the existence of the firm, not only for the competitive position.

Brandon-Jones et al. (2014) argue that in complex supply chains, visibility capabilities create resilience and robustness, and therefore is a good investment, as it can be difficult to invest directly on resilience. They claim that investing in visibility is appropriate no matter if the geographic spread is big or small, and no matter if the reliability lead-

times, or supplier differentiation are big or small (Brandon-Jones et al. 2014). In simple supply chains on the other hand, it is more possible to invest directly in resilience without needing to invest in visibility, and in that situation, visibility offers only limited benefits for resilience (Brandon-Jones et al. 2014).

Christopher and Peck (2004) state that strategies which keep many options open will offer good resilience. This way one disturbance has limited effects, as it is possible to use another option. This is very similar to the idea of high flexibility. In the same paper, they say that one of the key requirements for improving resilience is understanding the network of supply chain, with the connections to suppliers and their suppliers downstream. This will help in recognizing those critical paths in the chain, which might be highly vulnerable, or sources of vulnerability to the whole chain. Vulnerability can come from capacity limit or from having no alternative options in the case of disturbance.

Christopher and Peck (2004) explain further about critical paths in the supply chain and tell some of their characteristics: long lead-times with long time from order to delivery, being single source with no alternatives, having poor visibility with no or little shared information in the chain, or having high levels of identified risks. This points out how RM strategies can be important for supply chain resilience, as identifying critical paths or nodes in the supply chain allows making improvements or preparations in case of disruptions. Identifying critical paths and preparing and plans for disruptions could be done together with other members of the supply chain. This makes use of their knowledge, and it highlights the importance of collaboration, information sharing, and knowledge management, with RM and further improving resilience.

Christopher and Peck (2004) also go into explaining some aspects of supply base strategies in the SC and argue that single sourcing can be cost-effective and good for quality, but risky for resilience. They say how for multiple products, single sourcing by one product (or by one factory) can offer the benefits of single sourcing, without risking the loss of resilience on the way, compared to choosing to single source with a wide range of items from the same source. However, it is worth pointing out that multi-sourcing with high level of suppliers can lead to increased complexity of the supply chain, which can cause decreased resilience if not managed properly.

Kang Zhao et al. (2011) point out that making changes in businesses' own organization's network level does not always turn into also globally resilient network. For this reason, building resilience in the entire supply chain is not so simple in most times. Only a limited number of changes and improvements can be made on the level of a single organisation. For larger impact, the changes should be made on the whole supply

chain level. It is argued by Adobor (2019) that highly SC oriented firms will create more possibility for high supply chain resilience. This can be because the supply chain perspective is already an integral part of the firm's decision making and operations. Also, it can be possible that highly SC oriented firms have already high levels of working together in the SC present, and that makes it easier to make changes on the SC level.

3.4.5 Summary

From the text before, it can be seen how integration and coordination and control are very similar together. The only 3 papers which talk about integration and coordination and control both are literature reviews, which take the elements from other papers, instead of creating a new framework or concept (Pereira et al. 2014; Tukamuhabwa et al. 2015; Piera et al. 2020). In many papers, only one of the two, integration or coordination and control, is talked about. The difference between the two elements seems to be very minimal. In the papers where coordination and control is only one mentioned, the focus is more on the control aspect, in the ability to measure and make changes along the entire supply chain (Christopher and Peck 2004; Spiegler et al. 2012; Gunasekaran et al. 2015; Jain et al. 2017). Very similarly integration is presented as a capability of having compatible processes and ways of doing things in the supply chain and is more focused on coordination instead of control (Carvalho et al. 2011; Brusset and Teller 2017; Chowdgury and Quaddus 2017). As both elements are very similar together with only minute differences, after this point in this thesis, those two elements are combined in one element, called coordination and control.

It also can be seen that trust is only a supporting element with working together and does not directly affect resilience. Also, trust is not something that can be directly increased, and measuring it is challenging. In this thesis and the empirical research, trust can be left out for these reasons, as it offers nothing meaningful to research trust, instead of other elements about working together. However, the lack of trust as a barrier to other elements can be important and should not be forgotten.

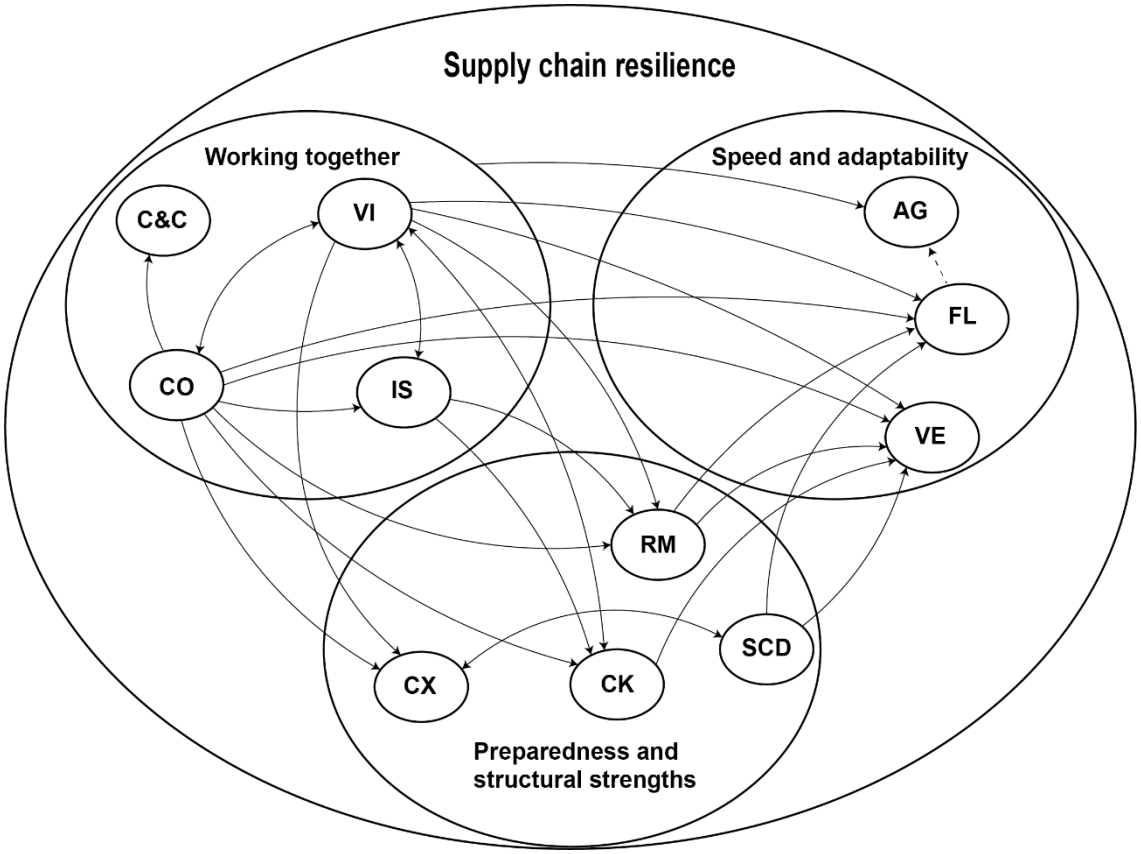
Financial strength might be an important part of SCRES, but it is an important part of all operations in a business, and not related only to SCRES. In addition, there is not much material in the literature to support the role of financial strength in SCRES. Therefore, researching financial strength in the context of SCRES in this thesis serves no purpose, and it can be also left out from this analysis.

Redundancy, as stated before, is a route to flexibility, not directly to SCRES. Because of this, there is no need to keep redundancy as a separate element to be analysed

from now on. Redundancy is still under the element of flexibility, so separate element from it would create unnecessary repetition.

For sustainability, there is very little information in the literature. The information found about sustainability does not clearly say and prove the role of sustainability in the supply chain resilience. It also strongly looks like all the aspects of sustainability which are related to resilience, might be also sub-categories of risk management. For this reason, it is reasonable to not analyse sustainability any further in this thesis, as it would take the focus into different direction.

From the observations in this chapter, we can build a visualisation of the results as a summary. In the picture 5 below, SCRES, groups of elements, and the remaining elements in each group are drawn. The relationships between each element are drawn as arrows, which point to the element they affect.



Picture 5. *Framework for SCRES and its elements with their relations.*

In the picture 5, FL = flexibility, VI = visibility, AG = agility, CO = collaboration, IS = information sharing, C&C = coordination and control, SCD = supply chain design, RM = risk management, CK = company's knowledge, VE = velocity, CX = complexity.

It can be seen from the picture 5 how elements from the group of working together affect elements in all groups. However, elements in the group preparedness and struc-

tural strengths are almost solely affected by elements of working together. The elements in the group of preparedness and structural strengths also influence the elements of speed and adaptability. This suggests that working together acts as an enabler for all other elements, and it together with preparedness and *structural strengths* are enablers for *speed and adaptability*. In the table 4 below, there is a collected summary of methods to increase the capability for each element.

Table 4. *List of ways to enhance each element of SCRES.*

Element	***Ways to enhance***
Visibility	*Information sharing, trust, collaboration, knowledge management, integrated capabilities*
Collaboration	*Visibility, trust, integrated capabilities, systematic goal of closer working together*
Information sharing	*Trust, collaboration, visibility, strong relationships*
Coordination and control	*Monitoring and measuring systems, collaboration, building integrated systems between members, working together in systematic way*
Flexibility	*Create options and redundancy (suppliers, spare resources, spare capacity, spare inventory), risk management, SC structure, collaboration, visibility, flexibility in products*
Agility	*Communication and cooperation in SC, create product flexibility*
Velocity	*Streamline processes, reduce in-bound lead-times, reduce non-value adding process times, visibility, collaboration, risk management, knowledge management, SC structure*
Supply chain design	*Lower complexity, less centralized nodes, create alternative suppliers and nodes, balance between efficiency and security*
Risk management	*Risk management culture on every level of organisation and SC, information sharing, collaboration, visibility, spot market options, backup suppliers*
Company's knowledge	*Collaboration, information sharing, visibility, integrated knowledge management systems*
Complexity	*Collaboration, visibility, continuous monitoring, SC design, focus on complexity during product design, supplier selection*

3.5 Supply chain resilience on performance

The effect of supply chain resilience on performance is not talked in most of the papers in this literature review. Only in few papers the performance is given some attention. In most of those papers, however, the performance aspect is only mentioned very briefly. Some papers simply conclude that SCRES leads into higher SC performance and stability (Mandal et al. 2016; Adobor 2019). At least in theoretical level, high SCRES will lead to better performance during a disruption, as it makes recovering from the disruption more efficient. Less clear aspect is the relation between costs and benefits of resil-

ience, and the effects of resilience on performance during normal operation without disruptions.

Chowdgury and Quaddus (2017) argue that both proactive and reactive resilience capabilities need to be used for having better resilience and performance. They say that proactive resilience capabilities will satisfy customer needs, and reactive capabilities will help to respond to changes in the environment. According to Wieland et al. (2013), customer value is said to be the most significant performance dimension gain from resilience. It includes customer specifications and customer satisfaction. Other performance increases according to Jüttner and Maklan (2011) and Pereira et al. (2014) come from decreased risks, as Information sharing, and collaboration can mitigate risks in the supply chain. Collaboration is also said to promote product quality and improve delivery times (Carvalho et al. 2012).

In their paper, Spiegler et al. (2012) talk about the trade-off between resilience and costs. They say it can be expensive to have enough flexibility and redundancy for good resilience, but also the lack of resilience creates costs or lost revenues in form of poor customer service, vulnerability to disruptions and lack of control. These all are very difficult to measure and control, compared to the costs, which are very visible. For this reason, it can be very difficult to see the benefits of investments in resilience, especially if there is not a way to measure and control it.

Flexibility is said to help with staying on cost and revenue targets, as it can help to shift to use more cost-effective sources and multi-sourcing, and to reallocate capacity to optimise utilisation (Jüttner and Maklan 2011; Carvalho et al. 2012). Flexibility does also simplify planning and make it possible to react faster to changes and select best ways to utilise resources (Gunasekaran et al. 2015; Carvalho et al. 2012). Workforce flexibility decreases bottleneck times and can reduce response times (Carvalho et al. 2012). Higher velocity helps to stay on revenue targets, as it enables fast access to regional capacity and fast response to changes in demand (Jüttner and Maklan 2011; Gunasekaran et al. 2015).

According to Carvalho et al. (2012), resilient practices will increase information frequency with the help of higher demand visibility. Increased visibility is also argued to improve decision-making by allowing to see problems better, and to choose other suppliers when needed and mitigate the negative effects (Jüttner and Maklan 2011; Carvalho et al. 2012). Carvalho et al. (2012) tell that increasing supply chain resilience increases integration level and reduces production and transportation lead times. These

can be seen as ways in which resilience affects performance in normal situation with no disruptions happening.

In summary, SCRES has clearly important effect on performance in individual firm and in the supply chain, even in times without significant disruptions. During a disruption, SCRES can show its benefits very clearly by allowing faster recovery back to normal operation levels. In other times, SCRES can decrease risks and increase stability, as it enables faster reaction times and Improves spotting of disruptions earlier. It also can increase operational performance by increasing customer satisfaction, responses to demand, and allowing faster delivery times. And lastly, it can increase economic performance by enabling cheaper sourcing with supplier selection and multi-sourcing, and reallocation of capacity. Sometimes it is difficult to see the benefits of SCRES on performance, as the benefits might not be very visible, especially in times without notable disruptions. For this, measuring of resilience is needed.

3.6 Measuring resilience

In this chapter the goal is to go through methods of measuring SCRES and its effects. The goal is not to give complete instruction for measuring resilience here, but to give a general idea of ways to measure resilience.

Measuring resilience is not an easy task, as it cannot be seen directly, and it cannot be collected and presented with a simple number. Some articles discuss measuring SCRES, but in most cases it gets little attention. In the paper by Soni et al. (2014) it is the primary focus of the article, and in the papers by Piera et a. (2020), and Chowdgury and Quaddus (2017) it is theme too. Carvalho et al. (2012) and Carvalho et al. (2011) go through measuring performance, which is affected by resilience. Wieland et al. (2013) and Spiegler et al. (2012) talk about methods of measuring SCRES, but it is not the main theme.

According to Carvalho et al. (2012), supply chain resilience affects operational performance, which includes responsiveness and flexibility, and economic performance, which includes management of costs related to inventories and redundancies. For measuring operational performance, Carvalho et al. (2012) suggest measuring product quality, delivery speed and accuracy, time, flexibility, and inventory levels. For measuring economic performance, they recommend measuring cost, value added, operating profit, return on asset, cash cycle, and efficiency. The most important measurements are told to be quality to customers, customer service, and time to market (Carvalho et al. 2012). This way of measuring is only focused on performance and is more aimed to

measure it during normal operations with no disruptions, or only small day-to-day disruptions. It lacks the ways to measure resilience towards disruptions efficiently.

Spiegler et al. (2012) suggest that the best performance measurements for SCRES are production on-cost and lead-time. Carvalho et al. (2011) very similarly argues that the most important groups for measurement are lead-time, customer service, cost, and quality. This is very close to what Carvalho et al. (2012), and Spiegler et al. (2012) claim. Piera et a. (2020) also list different metrics for measuring SCRES and found 33 metrics related to it. Minimum recovery time is the most important measurement for SCRES, followed by levels of safety stock, and customer service rate (Piera et a. 2020). For these, it is not specified more how to measure the metrics. This is clearly a common problem in these papers: it is known which things are important and need to be measured, but it is not clear which ways can be used to measure them effectively.

Wieland et al. (2013) have a slightly different approach and say how each element can be measured independently. They used questionnaires related to the elements, with a scale from 1 to 7. Each question is given weight based on its importance. With this method, it is possible to calculate some measurement number to SCRES, but it can be inaccurate, as it measures rather each element, not directly SCRES. It also can have inaccuracy if questions are not answered critically and truthfully.

Chowdgury and Quaddus (2017) claim that measuring SCRES can be done by measuring recovery time, costs, disruption absorption capability and ability to reduce the impact of the losses during disruption. This however would need a disruption to happen for taking measurements, or other methods such as simulating of disruption, which can create inaccuracies.

Out of all the papers in this literature review, Soni et al. (2014) give the most complete method for measuring SCRES. The first step is to calculate “Supply Chain Resilience Index”, SCRI, by using a matrix of resilience elements and their interactions with each of the other elements (Soni et al. 2014). In the paper by Soni et al. (2014), there are 10 elements of resilience presented. Each element would be given an assigned value on how high it is in the firm, and each interaction between two elements would similarly be given value, based on how strong the interdependency is. Calculating their interactions gives 10! different terms. Details of the calculation are not relevant for this thesis. In this method, the interaction between each element is considered, which makes this method more sophisticated than other methods, but also increases the complexity.

Maybe the best way to measure the SCRES itself is by measuring each element individually and giving some value to resilience based on those measurements. One

downside in this approach is that those measurements can rely heavily on subjective answers, not facts or numbers. With clear definitions and multiple persons doing the evaluation, this method can have increased accuracy.

Measuring the effects on performance is also possible, and arguably useful. This way the costs of resilience can be justified more easily when the benefits of resilience can be seen. Costs, profits, and speed are easy to measure, as they are in a form of comparable numbers. Customer service, on the other hand, needs to be to a form, where it can be more easily compared and measured.

4. EMPIRICAL RESEARCH

The structure of this chapter is as follows: 4.1 introduces the material about supply chain and disruptions during the pandemic. The material for the chapter 4.1 is collected from literature, statistics, and last, from the interviews. After that, in chapters 4.2, 4.3, and 4.4 the elements of supply chain resilience in each of the interviewed firms are analysed in the groups of “working together”, “speed and adaptability”, and “preparedness and structural strengths”. In the chapter 4.5, these findings are collected and compared between the firms. The methods of the interview research are explained in the methodology chapter 2.2.

4.1 COVID-19 pandemic and its effects on supply chains

Pandemic as a disruption can be very damaging for supply chains and to businesses, as it can affect many locations worldwide. One characteristic in pandemic is the nature of its spread: it is not instantaneous, the same way how many other disruptions can be, but builds up from a slow start to larger disruption. Disruptive effects of pandemic can happen fast, as they can be often resulting from governments setting regulations and limitations.

The focus in this thesis is on the pandemic of COVID-19. COVID-19 is a highly infectious virus, which causes respiratory problems, and other symptoms (Rowan and John 2020). The illness can be fatal. This combination makes it a significant public health concern. Personal and protective equipment can be used to prevent the spread, which has resulted in shortages and disruptions in the supply for those, as they are difficult to reprocess with disinfection, and often need replacement (Rowan and John 2020).

COVID-19 created a shock in the demand for food supply, as a result form consumer behaviour, namely panic buying (Hobbs 2020). For this situation, the just-in-time method for restocking was not durable strategy, and the supply chains were not prepared to ramp up supply in fast enough pace (Hobbs 2020). According to Hobbs (2020), supply side experienced multiple disruptions: labour shortages, transportation disruptions, and disruptions in border crossings. This example is from the food industry, but especially from supply side, all the same issues concern other industries as well. COVID-19 has been serious disruption for all industries, as 94% of all companies in the Fortune 1000

list told to be facing disruptions in the supply chain because of COVID-19 (Sherman 2020)

According to Craighead et al. (2020), pandemics, such as COVID-19, differ from most other disruptions in 3 dimensions. First by scope, which is in typical disruption very local, whereas pandemic has a global scope, in most of the world in most of the industries. Secondly by spillover, as typical disruption unfolds with large sudden impact, which dissipates into smaller effects. Pandemic instead spreads as waves in different regions, requiring responses from governments, which causes more disruptions globally as time passes. And last, typical disruption affects only supply or demand, rarely both significantly. In pandemic, supply and demand are both forced to extreme highs and lows. As an example, panic buying caused household items to face sudden demand, while new car demand disappeared completely in the United States during COVID-19. (Craighead et al. 2020)

Singh et al. (2020) go into detail how COVID-19 is affecting severely tourism industry, aviation industry, automotive industry, construction industry, telecom sector, healthcare industry, and food industry. It put a high pressure on healthcare supply chains, as protective equipment and pharmaceuticals were needed urgently all over the world at the same time. COVID-19 outbreak had a high impact on manufacturing operations and supply chains globally, which raises the need for a resilient supply chain for rapid supply chain recovery. (Singh et al. 2020)

United Nations estimates based on their statistics that on average, manufacturing industries have lost 18% of their production in high-income countries, 24% in upper middle-income countries, and 22% in lower middle-income countries (UNIDO 2020). They also go into more detail about different industry sectors, saying how textile and apparel industries suffer the most, and firms in chemical and plastic industries face lesser effects. In most industries, the fall in demand is the biggest cause of problems from COVID-19, but also logistics problems and disruptions in the value chain are told to be a big problem for many firms (UNIDO 2020).

In Europe, European Commission has analysed the financial effects of COVID-19 in the world and in EU countries. They estimate that the pandemic will cause a 9,7% decrease in global trade in the year 2020, 9,2% decrease in exports of goods and services in the EU area, and 8,8% decrease in imports in EU area (European Commission 2020). The amount of export and import only accounts for in and out of EU economics zone and does not include the trade between EU nations. In Finland, in the second quarter of 2020 export decreased 8,7% from the last quarter, and 12,0% year-over-

year (Official Statistics of Finland 2020). Similarly, imports decreased in the second quarter of 2020 9,8% from last quarter, and 12,7% year-over-year (Official Statistics of Finland 2020).

For the results of the interviews, the structure of this chapter follows a similar structure as the grouping of elements in previous chapters. First the general effects of the pandemic to each firm are examined, and the general actions the firms have taken in response to the pandemic. After that, there is one sub-chapter for each of the element group: working together, speed and adaptability, and preparedness and strengths.

Each individual interview is analysed separately, making no uniform hard rules for making further conclusions from the answers. This means e.g., that simply mentioning a specific keyword or subject in the interview is not enough for making conclusions about that subject, but conclusions are made by analysing whole answers together with the context and its connections to other answers.

Scoring of the elements is used to help to keep track of and comparing of each element in each firm. The scoring is based on four different ratings: 3 different scores and one option for not giving a rating at all. With this available material, it is not reliable to use more accurate rating scale. Lowest rating is 1, which means that the element is in an undesirable state in that firm, and there is a lot that could be improved regarding it. Next score is 2, which will be given when the element is in good state, but still has multiple details which are not as good as would be desirable. This score 2 can also be given if there are some positive and some negative matters regarding the element, if the balance is not clearly a lot in either direction. The best possible score is 3, which means an excellent state of the element in the firm. This does not mean the state is perfect, or that it should not be improved, but that it is in an excellent good state within reasons and can still have some negative aspects in it. The final rating is “not rated” (NR) and means that it is not possible to give rating, which is reliable enough for the element in the firm. This can be given when there is too little information about the subject, or when there is reasonable cause to doubt that the information is not reliable, or it is too one-sided. This rating system does not consider more details about the firm, for example about the industry or size. Analysing the differences is done later in the chapter 5.

The SCRES and resilience alone were rather little-known terms in the interviewed firms. For the firms A, B and D, resilience was not known or used term and concept before the pandemic, and they did not use any alternative term with similar meaning. Firm B specifically mentioned how they take needed actions, which might be very similar to

what the concept of resilience means, but they do not label it under any term. For the firm C, resilience was known term, but not used as itself. Instead, in firm C, they used risk management and business continuity terms with somewhat similar and overlapping meaning.

For the firm A, COVID-19 pandemic caused the demand to drop slightly, and sales during this time have been less than one year ago. Their goal is to increase sales year-over-year, so the effects of the pandemic in demand are clear and noticeable. However, according to the interviewee, the decrease in demand has not been as bad as for many other firms. Besides decreased demand, firm A has experienced slowdowns in projects which needs collaboration with customers, as it has been more difficult to coordinate the work together with customers. In the early couple of months of pandemic, there was also some lack of materials for firm A, but this did not cause big issues. The biggest effects for the firm A were related to deliveries, as globally lowered air cargo capacity made it more difficult to transport products to customers, which caused delays in orders. For the firm A, the most important actions against the pandemic were being proactively much more in contact with its suppliers and increasing knowledge about their situation actively and buying 3 months' safety buffer of supply materials in their own warehouses.

For the firm B, the pandemic caused some actions very early on, as they have suppliers in China, where the COVID-19 pandemic spread originally. In short, they made sure the supply chain from China stays functional and without disruptions. When the pandemic advanced to Europe, they again took similar actions with their European suppliers, and made sure deliveries will not be hindered. For firm B, the pandemic caused a high impact on demand: initially there was no noticeable change, but after countries introduced lockdowns and other measures to fight against the pandemic, their demand dropped significantly. This led to a decrease in their material needs and purchases, and later also their production had to be decreased to meet the market situation. These changes were visible for the firm almost immediately when the demand dropped, and their reaction to it was fast.

The firm C has a very global presence, and has its own facilities around the world, so the effects of the pandemic were both global and local. Around the world, local effects of the COVID-19 decreased their demand and created delays in original customer purchase plans. Some of their own and their subcontractors' production facilities had to be temporarily closed, or operate at lower output, because of the drop in demand, and local restrictions. This affected the logistics needs.

The firm C took plenty of actions during the pandemic. They made sure that they always have timely and correct information from around the world, from suppliers, customers, and all partners. The firm's own planning cycles were shortened from one month to one week, so spotting problems and reacting to changes would be faster paced. Extra attention was given to each country's specific situation related to customers conditions and their buying capacities. In the interview, one example of this was given: they made sure that if closed borders affected customers' situation, if they for example have many cross-border workers, how it might affect their demand for Firm C's products. All this at the same time is compared with their own supply side: are there some limitations from regulations or production capacity for the supply? Firm C made actively backup plans for situations where one supplier faces disruptions. They made sure that there should always be an alternative supplier, or some plan if it happens. With logistics, the same approach was taken. In firm C, they were finding proactively alternative solutions, in case of disruptions with current plans occurs. In general, the firm C's plan with the pandemic was using closer collaboration with all parties and increasing their readiness for different disruptions.

For the firm D, the pandemic caused problems to make deliveries, because some of their customers downscaled or stopped their production, which decreased their customers' need for the product. For this reason, their customers did not want to receive orders, so many of the firm D's deliveries were delayed. Firm D saw some positive effects of the pandemic, as the availability of some materials they needed increased, because the demand from others for these materials in the same area decreased. Other big effect of the pandemic was the drop in new orders: first to the level of about 25% of normal levels, then later in the beginning of summer 2020 to 50% level, and at the end of the summer back to 75-100% levels compared to the normal. Production in some factories, however, stayed on normal levels, as before the pandemic there was a large production backlog. Later in the pandemic, layoffs throughout the organisation resulted in problems in the supply chain, as the material supply decreased too much. For the firm D, the only significant managerial action caused by the pandemic was layoffs. Some of this can be explained by the fact that almost all their supply chain is within their own organisation.

4.2 Working together

For the firm A, the ways to detect problems and disruptions is closely related to working together with the suppliers: the buying team will communicate more often and closer with them and get more updates of their situation. Firm A also mentioned how they get

some information of supplier's situations by confirmations on purchase orders, as they cannot confirm orders, if they are uncertain if they can fulfil orders. Firm A also sends sales forecasts to the most important suppliers, who are asked to confirm them. Similarly, with these forecasts, the suppliers who might have problems fulfilling the demand in forecasts cannot give confirmation. For firm A, the typical ways to share information has been personal email and direct contact. Sometimes surveys are used, but with lesser role. Firm A used some collaboration methods during the pandemic, as they increased their emergency stock levels significantly on all needed materials with even slight chance of supply problems, and actively collaborated with logistical partners with planning and finding solutions. In the interview it was mentioned that they have spotted problems also in deeper than first-tier suppliers, and the information of this comes mainly through own their suppliers. The ratings for this group for the firm A are listed in the table 5.

Table 5. *Rating of elements in "working together" group for the firm A.*

Element	*Rating*	*Reasoning*
Visibility	*3*	*They share openly the needed information with the suppliers and get information from the supply chain. The active communication creates ways to detect disruptions and see the severity of it.*
Collaboration	*2*	*Collaboration done with at least logistical partners, and as a tool for problem solving, like increasing emergency stock levels. Does active collaboration with customers.*
Information sharing	*3*	*Relevant information about demand, forecasts, general situation, and plans is shared with the suppliers on multiple different channels.*
Coordination and control	*2*	*They have plans and strategies for disruptive situations, especially for preventing disruptions and possible escalations. No reason to believe they cannot act according to the plans.*

For the firm B, the reactions to the pandemic were proactive before any disruptions in the supply chain or supplier network were noticed. For this reason, faced no direct disruption in their supply chain. Usually, if there are some disruptions or unusual situations in their supply chain, it is noticed by communicating with their partners, one by one, on a personal level. The firm B communicates their own demand directly to their main suppliers, so they know to prepare for it. Also, other communication with all their suppliers can be described as active, even in normal situations. During the pandemic, firm B had only slight amounts of collaboration within their supply chain, mainly decreasing of purchases or changing purchase orders. They did not spot any problems deeper than their first-tier suppliers in their supply chain, and typically that information would

be received through their own suppliers. The ratings for this group for the firm B are listed in the table 6.

Table 6. *Rating of elements in "working together" group for the firm B.*

Element	*Rating*	*Reasoning*
Visibility	*2*	*Communicating about demand, and being able to gain information about disruptions, or lack of disruptions, fast is a good sign of high visibility.*
Collaboration	*NR*	*There is no proof of showing any collaboration, other than changes in purchase orders. It is worth to note, however, that some forms of information sharing, especially if done in real-time, is one form of collaboration. The material is too limited for making further conclusions.*
Information sharing	*3*	*The firm B has active information sharing with their suppliers, and openly communicates about the demand, disruptions, and general situations proactively.*
Coordination and control	*2*	*The firm B proactively reacted to the pandemic, before any disruptions occurred, and thus preventing disruptions. Similar plan and actions were done again in Europe, as the pandemic spread.*

In the firm C, detection of problems mostly relies on their own organisation. As they have a very global presence, this is possible and working strategy. For them, the first information about the pandemic was gained through media, and this caused risk analysis evaluation in the organisation. They looked for vulnerabilities before any problems occurred. Part of this process was communicating with suppliers and investigating what problems and vulnerabilities they might have and finding out on what level their operations can continue in which situations, in case of disruptions. In addition, in the risk analysis process was included finding out local authority regulations and guidelines related to the pandemic. This was done by either their own organisation, or if needed, with the help of own suppliers.

Communication during the problems of pandemic has been done in many forms in the firm C. They used mass communication by email about relevant information to all suppliers, in which they inform about their own situation. When problems arise, communications were handled directly on a personal level. For second- and deeper tier suppliers, the firm C has few strategic suppliers who are in direct contact with them. They did not detect problems with deeper than first-tier suppliers during the pandemic. The ratings for this group for the firm C are listed in the table 7.

Table 7. *Rating of elements in "working together" group for the firm C.*

Element	*Rating*	*Reasoning*
Visibility	*3*	*Active communication, and receiving and sharing information about their suppliers', customers', and own situations is a sign of excellent visibility. They also have plans which focus on these aspects.*
Collabora-tion	*3*	*They are actively in contact with partners, not only to give and gain information, but to find solutions and solve problems. They have the attitude of working together for the good of all parties. Increasing collaboration was part of their plan in reacting to the pandemic.*
Information sharing	*3*	*Information sharing in the firm C is very active on all levels: within the organization, with suppliers, with customers, and even some amount with authorities.*
Coordination and control	*3*	*The firm C has global influence, and clearly good planning process. Their coordination and control in the supply chain and whole organization seems to be great based on the interview. Their actions included lots of planning and preparing for different scenarios and even shortening their planning cycle to make reaction times faster.*

In the firm D, the pandemic did not have immediate effects. They noticed its first negative effects only when there was a drop in the new purchase orders they received. This means that the detection of disruptions was not reliant on communication or information sharing with supply chain partners. The ways firm D communicates within the supply chain is typically personal email, and sometimes remote meetings. Communication happens when it is needed, and there are no regular status checks with these instruments. In the organisation's internal IT systems, it is possible to notice problems as delays in some part of the supply chain. This is rather different from the other firms in this chapter, as firm D has its supply chain mostly within the organisation itself. The firm D did not do any special collaboration related to the pandemic. On other levels of their supply chain, later during the pandemic, the layoffs done at the earlier months started to have some negative effects. This resulted in a shortage of materials, which affected their own production capacity. The ratings for this group for the firm D are listed in the table 8.

Table 8. *Rating of elements in "working together" group for the firm D.*

Element	*Rating*	*Reasoning*
Visibility	*2*	*Visibility in the firm D seems to be at good levels. They get information about problems from the supply chain within their organization fast and reliably. From customers' side of the supply chain, visibility seems to be lesser.*
Collaboration	*1*	*Collaboration in the firm D is very different to evaluate compared to the other firms. Having supply chain more in the own organization gives much better readiness to collaborate within the supply chain. Collaboration between firm D and other firms seems to be rather small, or at least in the interview there was not any proof of that.*
Information sharing	*NR*	*Like collaboration, information sharing in the firm D is very different to evaluate, as the supply chain is more integrated within the organization. This gives much different requirements for sharing of information, and in the interview, the focus was not so well related to this.*
Coordination and control	*2*	*From the small amount of information in the interview, it could be understood that their internal supply chain within the organization seems to have a good level of coordination and control. Outside of their own organization, their coordination and control seem to be weaker, but for this, it is possible the interview did not function as a reliable source.*

4.3 Speed and adaptability

The firm A claims they have good preparedness to act fast when it is needed. They are continuously monitoring market situations, and their own and suppliers' situations. They monitor actively for example the lack of materials, and they have action plans with various escalation tiers ready if there is need to react. Changes in the demand are also monitored closely, and this makes it possible to prepare better for upcoming demand with suitable production capacity and amount of materials. This gives them good readiness to spot disruptions early and act correctly. They also say they have faster delivery times compared to their competitors.

According to the interview, the firm A has flexibility in production and logistics. This flexibility originates largely from the type of the firm, as their production capacity is not supposed to be their limiting factor, and they do not even try to achieve high capacity utilisation rates. Some of their contracts also have production flexibility in them, but not all. The firm A prepares their suppliers for fast reactions by having them to keep an emergency stock of critical components the firm A needs. Typically, the firm A does not have multiple supplier options for their needed materials and components. They also do not have direct preparedness to move production to a completely different facility,

but if needed, they should be able to rent a new facility, and move to a new location. The ratings for this group for the firm A are listed in the table 9.

Table 9. *Rating of elements in "speed and adaptability" group for the firm A.*

Element	*Rating*	*Reasoning*
Flexibility	*2*	*Their lack of redundancy in supplier options is probably the biggest shortcoming in this element. However, they have good flexibility in production, logistics, and contracts, and utilising an emergency stock.*
Agility	*3*	*Based on the interview, agility in the firm A is great. For good agility, the most important factor is being able to react fast, in this context, to disruptions. The firm A can react fast and have plans to support this capability. Their habit of monitoring things regularly also is a critical part of agility.*
Velocity	*2*	*In the firm A, there are some indicators that velocity is good, such as fast deliveries, and good preparations and plans for disruptions. The firm A also themselves claim they gave good preparedness to act fast.*

In the interview, the firm B stated that their decision making is quick, partly because of the structure of the company. They claim to have an exceptional ability to do fast changes for changing needs of situations. During the pandemic, they have secured critical components in emergency stock by either in their own or supplier's facilities. For the firm B, big customers give flexibility in orders, smaller customers less often do so.

The firm B has broad supplier network around the world. Most of the components they need are from only a single supply source, but few components have multiple supplier options. With some suppliers, the firm B has an agreement that the supplier always has a certain level of stock of components, but some suppliers only make components ready when they are ordered. For the firm B, method of preparing suppliers for disruptive and unusual situations is keeping them up to date on all situations and sharing sales forecasts with the main suppliers, especially with those suppliers who have a long supply chain and delivery time. The firm B has neither own nor supply chains' backup facilities, or other action plans in case of total disruption in their own facilities. According to the interview, it is possible for them to move manufacturing to another location, but it would take a long time and they have not prepared for it. The ratings for this group for the firm B are listed in the table 10.

Table 10. *Rating of elements in "speed and adaptability" group for the firm B.*

Element	*Rating*	*Reasoning*
Flexibility	*2*	*They have some amount of redundancy in supplier options. They have flexibility with some customers, but not with all. Use of an emergency stock is a good sign. Perhaps their most critical shortcoming in flexibility is that they have very little options in case of less demand from their customers, as it was explained earlier how the pandemic affected their business situation.*
Agility	*3*	*They claim to be able to make fast decisions and act fast, which shows great agility. They took proactive actions during early stages of the COVID-19 pandemic, which also shows a capability of good agility.*
Velocity	*3*	*They can make fast decisions and act fast. They also take in their plans into account how fast different goods move in the SC, which does not directly mean good velocity, but it shows they have ways to mitigate the lack of good velocity in some areas.*

The firm C clearly has a good focus on their speed and adaptability, and it is apparently an area they pay attention to and try to improve. According to the interview, their organisation has good readiness to react fast to changing situation, and their organisation structure is well fitted for acting fast. During COVID-19 pandemic, their financial results have been good, which might show that they have done things right, and took correct actions at correct time. In the firm C, their own production capacity is rather flexible. It is possible to lower production output without problems or apparent limits. To increase production rate, it is easily flexible locally about 20% with overtime work, depending on the factory. Increasing production output beyond that is possible, but they require a few months' preparation for hiring extra shifts to work. Regardless of their own production flexibility, all the components for final products are needed. This means that at the same time they need to make sure their suppliers are ready to deliver more needed components or have a similar capability to increase their production capacity.

The firm C has systematically tried to get rid of all single sourcing situations with components and parts, so it is not relying on only one supplier with anything component, as they have recognized it creates vulnerability. Geographical supplier diversification and flexibility is also recognized to be important, and in their opinion will be even more important in the future, for which this pandemic, recent trade wars, and increase in tolls are a proof of. These can make certain geographical locations much more difficult to do business with, buy from, or sell to, and increase costs of doing business in certain locations. Having many options gives the possibility for additional cost-efficiency, and possibility to choose more ecological options.

For the firm C, emergency stock is very important with some components, but it is only used with very few critical components, as it increases costs. Because of the nature of their business, there are lots of time to react for future component needs, so emergency stock is less important in their case. In serious disruption situation, for the firm C it is possible to move production to another facility of their own if needed. There are, however, some limitations related to details in their products, and all products cannot be manufactured in each facility. This can be solved by using multiple different replacement facilities together for the original facility. The ratings for this group for the firm C are listed in the table 11.

Table 11. *Rating of elements in "speed and adaptability" group for the firm C.*

Element	*Rating*	*Reasoning*
Flexibility	*3*	*They have flexibility in production, supplier selection, geographical locations for both production and suppliers, as well as redundancy in suppliers, and having the capability to use back-up facilities in case of need. Use of emergency stock with critical components also increases redundancy. Their plans and attention with all these components of flexibility also tell how it clearly is in an excellent state currently.*
Agility	*3*	*They did react fast to the changing situation at the signs of risk of disruptions and were preparing on a big scale and were finding solutions for disruptions in all different parts of the supply chain, even before there were any signs of disruptions yet. They say they have readiness to react fast, and the organization structure makes it possible to act fast.*
Velocity	*3*	*Here, all the same arguments about agility can be used for the velocity in the firm C. From their clear drive to cost-efficiency, it could also be assumed that materials in the SC move rather fast, but there is no direct proof of it.*

As the firm D is in a very different industry and has different organisation structure than other firms in these interviews, it is understandable it has a very different situation with speed and adaptability. In the interview, firm D said to have limited capabilities to react fast to changes in the market. Simply if there is not enough demand, or not enough materials, their factories cannot produce anything. They do not make products to stock, but only make them when ordered. In addition, finding new customers for their kind of business would be long and possibly difficult process, especially for large customers. Also, their production flexibility is very limited in other ways. Regularly in the factories, only the order of production can be changed, which then changes the production schedules, so indirectly also production schedules have some flexibility. Changing of order production happens only in case of disruptions, for example lack of materials, or unexpected problems in production. For the firm D, it is in theory possible to switch to use another supplier, but this would be done with great difficulties. For the firm D, the

main supply line is kept inside the organisation vertically integrated, so switching to outside source would be out of the ordinary. In the firm D, small amounts of the production capacity can be allocated to other factories. Inside a factory, there is more flexibility, as production can be moved to another production line with relative ease. The ratings for this group for the firm D are listed in the table 12.

Table 12. *Rating of elements in "speed and adaptability" group for the firm D.*

Element	*Rating*	*Reasoning*
Flexibility	*1*	*Flexibility in the firm D is limited. They have slight flexibility in production planning and slight redundancy in backup facilities. Besides that, there is almost no flexibility at all in these aspects investigated in this thesis.*
Agility	*1*	*For agility, the firm D is in a challenging situation, mostly because of the industry. Their business is almost completely focused on heavy materials, not services or small specialised components. In the interview, it became clear that they have not much capability to react fast to changes and have very limited ways to change the situation.*
Velocity	*1*	*In the firm D, their geographical proximity with the entire supply network is a clear advantage for velocity. But other than that, their velocity is like their agility: they are not capable to react fast when it might be needed.*

4.4 Preparedness and structural strengths

In this section, the elements of SCRES are more difficult to evaluate based on the interviews and other available material about the businesses, because they are much less visible to outside, and even inside of the firm. Especially the element "company's knowledge" is difficult, and even pointless, to even try to evaluate, as it would be very unreliable and even unfair to judge company's knowledge based on only one interview of one person in the company. For this reason, rating and analysing a company's knowledge is left out completely. In this thesis, also the product complexity is not a possible aspect to evaluate, so it will be ignored completely. Other aspects of complexity are still considered, and complexity will be rated based on those. In addition, evaluating supply chain design is challenging, as there is very little access to relevant information about this subject in the firms. There is also not clear agreement on which kind of SC design is the most resilient.

For the firm A, there were not any plans for global disruptions like pandemic beforehand. All their plans and actions were created after the pandemic started. According to them, the biggest strength in their industry is closely networked businesses who share information freely and work based on forecasts. Geographical closeness and excellent

knowledge of the supply network helps too, especially in disruption situations. According to the interview, good relations with important suppliers are also important tool for fighting disruptions. They also say that fast actions and agility are very important, so that the reaction speed stays good, and in turn they can minimise damages. Practical example of this is the action to increase stock levels when the availability of components and materials becomes uncertain. The ratings for this group for the firm A are listed in the table 13.

Table 13. *Rating of elements in "preparedness and structural strengths" group for the firm A.*

Element	*Rating*	*Reasoning*
Supply chain design	*2*	*The firm A mentions about closely networked businesses, geographical closeness, and that their delivery times are faster than what their competitors have. Perhaps geographical closeness creates vulnerability to local disruptions but protects from global disruptions. In this pandemic situation, geographical closeness in their case has been beneficial.*
Risk management	*2*	*The firm A increased stock levels as a safety measure, increased communication as a tool to gather information about risks, their good flexibility also lowers risks, and they have action plans and escalation ratings for recognising and reacting to problems. There are some places where RM could be improved, based on the interview. One example is their reliance on single sources for almost all their components.*
Complexity	*3*	*They do not have long global supply chains, which would increase complexity. Their major parts of the supply chains are very closely networked together and will share information and work together. They monitor the situation in their supply chain actively, which is one way to decrease its complexity.*

The firm B also did not have plans prepared for this kind of disruption in advance. They had general risk analysis and plans for different disruptions, but those did not cover global disruptions like pandemic. Within the organisation, there is a built-in action plan for disruptions, which gets its effectiveness from good agility. According to the firm B, in their firm and industrial sector, the most critical sources of strengths are good supplier collaboration, open communication, and capability for fast reactions. The interviewee believed that in this kind of global disruption situation, geographical location has little importance, as the effects are global. Operative practises which enable fast reactions are important, as they allow avoiding supply chain problems. The importance of supply network knowledge is an unknown sector for the firm B, but they believe it might be useful and could be important to increase their knowledge in that area. The ratings for this group for the firm B are listed in the table 14.

Table 14. *Rating of elements in "preparedness and structural strengths" group for the firm B.*

Element	*Rating*	*Reasoning*
Supply chain design	*NR*	*The firm B has global supply network with many single source components. They do their manufacturing in Finland but have suppliers all over the world. This means their incoming components need to come to Finland, and finished products ship away from one location. This can increase some of their SC node criticalities significantly. Because it is impossible to see the complete picture of their SC design, especially on its strengths, it is not fair to give a rating for it.*
Risk management	*2*	*Risk management in the firm B is at least on acceptable levels, as they mention having risk analysis, and plans for some kinds of disruptions. Their RM regarding the supply chain is not perfect, as they have global supply network, but apparently rather few components with multi-sourcing options.*
Complexity	*2*	*In the firm B, having mostly single source suppliers might create some risks, but it decreases complexity. Having very global SC instead of local increases complexity. However, they use other methods to mitigate complexity: they use monitoring and communication and have good visibility in the SC..*

For the firm C, there were plans for this kind of event beforehand. It was part of their risk management plans and business continuity plans. Those plans are on the level of the organisation and the supply network within the organisation, but not together with the outside supply chains. In these plans, there are factory specific plans included, which can minimize broader disruptive effects on the whole organisation in case of one factory faces disruptions. According to the interview, in this industrial field, global presence is a great strength, and established supplier relations and partnerships. These relations are very collaborative, and information flows both ways fluently and reliably. Cyclical nature of operations gives more time to act, as problems will not be realized to the end customer immediately. For this firm specifically, internal collaboration and planning processes in the entire supply chain are great strengths. The ratings for this group for the firm C are listed in the table 15.

Table 15. *Rating of elements in "preparedness and structural strengths" group for the firm C.*

Element	*Rating*	*Reasoning*
Supply chain design	*3*	*The firm C has suppliers all over the world, but the distances between supplier and the destination is not always very long, as they have factories in many locations. They have multiple supplier options for most of their components and can use the most suitable options on each occasion. Having many options and locations also usually decreases node criticality in the supply chain. Very worldwide supply network also decreases node density, which is an excellent protection against local disruptions in any specific location.*
Risk management	*3*	*In the interview it was mentioned many times, how RM and planning of things is part of their regular operation, and how they have taken many risk managerial actions during the pandemic. These are for example shortening the planning schedule, contacting suppliers and partners more often, and using risk analysis for finding vulnerabilities for making of backup plans for various events.*
Complexity	*2*	*The firm C has some complexity in its supply chain, but it is inevitable, as they are very global firm with many suppliers and facilities around the world. For managing complex-ty, they have good SC visibility, and their collaboration with SC members is also good. They keep controlling and monitoring situations and are prepared to take actions if something unusual is spotted.*

In the firm D, there was no action plan for this kind of disruption before the pandemic, and all the decisions and plans related to it have been done during the pandemic. According to the interview, in this industrial field and firm, geographical location brings some advantages: close distances in the SC enable short delivery times and lower delivery costs, and this gains more importance with heavy materials and products. For heavy metal industry, factories are typically in rural areas, and this might protect them slightly from global threats, such as in this pandemic, it did not spread as fast and critically in these locations, as in population centres. Also, for this reason, in these locations the restrictions set by authorities can be less disruptive for business operations. The ratings for this group for the firm D are listed in the table 16.

Table 16. *Rating of elements in "preparedness and structural strengths" group for the firm D.*

Element	*Rating*	*Reasoning*
Supply chain design	*2*	*SC design is at least in theory very good in the firm D, as most of its SC is integrated in the organisation itself and concentrated in small geographical area. One clearly negative aspect in the firm D and its SC design is node criticality: each node is very critical and has often no alternative options. This results in problems if one node has disruptions, and even small disruptions, problems, or delays will cause further delays in the SC.*
Risk management	*NR*	*For risk management in the firm D, there is very little information. In the interview, it was not clearly said anything directly about RM, and it is possible that risk management is done more in other parts of the organisation, and therefore the person in the interview could answer nothing related to it.*
Complexity	*3*	*For the firm D, low complexity is clearly one of the major benefits of their integrated SC, as it allows short distances, a moderate amount of SC players, and easy monitoring and visibility on the SC. In this firm also the product complexity could be evaluated, but it would not be scientific or fair to evaluate it only for one of the four firms.*

4.5 Cross-firm comparison

In this chapter, the results of the interviews are summarised. The results are collected into a table 17 below. The rating of "not rated" will be shortened in the table as "NR". There is also added simple "total score" from the ratings. For the "total score", the calculation is done by simply adding the points together, and "NR" being 0 points. This way of calculating of the total score is like the method Wieland et al. (2013) used, which was introduced in the chapter 3.6. However, Wieland et al. used weight on each element, based on the importance. It is obvious that not each element is equally important for SCRES, and this is not considered in the total score. It would be possible to research the importance of each element, and then use it to calculate the total score by weighting elements by their importance, but for this thesis, it is not a feasible option, as it would require completely new scientific theory as a support.

It must be noted that this total score formula is not reliable for comparing or calculating supply chain resilience, as it is simply adding together scores of each element. Noteworthy detail also is that when a rating is "not rated", it is calculated as 0. This might be a wrong approximation for the total score, even based on this material, because "not rated" can be given for other reasons, mainly lack of reliability. For this reason, also

Relative total score is calculated, as shown in equation (1), and it has a score in percentages. The formula for calculating Relative total score is as follows:

$$Relative\ total\ score = \frac{Total\ score-(10-X)}{(10-X)\times 2} \times 100\%, \quad (1)$$

Where X is the number of elements receiving the rating “not rated”. The 10 is the number of elements in total in this rating system. In the numerator, “Total score” is lowered by (10-X), which is the number of elements given other rating than “not rated”. This is done because the lowest given rating is 1, and with all elements rated as 1, the Relative total score starts from 0%, and can get the whole scale from 0% to 100%. In other words, this way the Relative total score does not “reward” from the rating of “1”. The same basic principle is used in the denominator in the equation, where (10-X) is used to calculate the number of elements rated, and it is multiplied by 2. This is done because the highest possible rating is equal to 3, but the total score is already decreased once by (10-X), so the denominator is multiplied by only 2. This equation means that with rating of 3 in all elements which are rated, the relative total score will be 100%. Same is true even if some number of elements receive “NR”, if all other elements receive 3. If all elements are rated as “2”, the Relative total score is naturally 50%. If all the elements would be as “not rated”, relative score would be also not rated at all.

In addition, this formula does not address in any way the relations between the elements. Some elements can strengthen others, some elements have bigger impact together with others, but not alone, and so on, but this either is not in any way addressed in the total score calculation. And last, because the firms are different in many ways, such as size, industry, and level of globality, it is not so simple to compare them directly element by element. For these reasons, the total score is not a scientific way to rate the firms, but merely a helpful tool.

Table 17. *Summary of ratings of elements in each interviewed firm.*

Element	***A***	***B***	***C***	***D***
Visibility	*3*	*2*	*3*	*2*
Collaboration	*2*	*NR*	*3*	*1*
Information sharing	*3*	*3*	*3*	*NR*
Coordination and control	*2*	*2*	*3*	*2*
Flexibility	*2*	*2*	*3*	*1*
Agility	*3*	*3*	*3*	*1*
Velocity	*2*	*3*	*3*	*1*
SC Design	*2*	*NR*	*3*	*2*
Risk management	*2*	*2*	*3*	*NR*
Complexity	*3*	*2*	*2*	*3*
Total score	*24*	*19*	*29*	*13*
Relative total score	*70%*	*68,75%*	*95%*	*31,25%*

From the table 17 it can be easily seen that with these elements, firms A and B are very similarly rated. The firm B is slightly more challenging to rate and has two elements as “NR”. The next immediately noticeable thing is how the firm C gets almost perfect score. There might be many reasons for this, and they are discussed in the next chapter. Also, the firm D is very noticeable, as it has the score that differs completely from any of the other firms. The firm D is also the most different firm from the other ones, and these details and reasons will be looked more closely in the next chapter.

From the results between the firms A and B, the firm B seems to have more velocity, while firm A has slightly more visibility, and possibly collaboration. The firm A faced a small but noticeable drop in sales and slowdown in cooperative operations during the pandemic. For firm A, some lack of materials was reported early in the pandemic, which supports the observation how compared to B, the velocity in the firm A is slightly smaller. For the firm B, there are no important observations to be made from this comparison. Their smaller visibility did not seem to have noticeable effects based on the available material.

The firm C is the only one with the best rated flexibility. If comparing their actions to all other firms, the differences are noticeable. They are the only one with a sizeable amount of redundancy in supplier options, and the most flexible production capabilities between their factories. Similarly, the firm C is the only one with the best rating in collaboration, and coordination and control. This is slightly less noticeable if comparing to the other three firms and can be partly because of their global size and influence. The

firm C, however, has much more evidence and material to show about their excellent collaboration and coordination and control within the SC than any other of these firms. The same way also risk management in the firm C has better rating than in other firms. For this, their size and global presence explains it a lot, and their industrial field. At their size, they should have plans for events and disasters, and they should be aware of risks and weaknesses. For the firms A and B, the requirements for risk management are maybe lower, as they could have some advantage from their smaller size. In smaller firms, taking big actions can be easier and simpler, and thus also faster. Supporting this statement, the capability of making fast decisions and actions was pointed out in the interviews with the firms A and B.

With complexity, there are two principal things to note when comparing all four firms. One is how larger firm and larger SC typically lead to more complex SC. This can be mitigated with some actions, such as collaboration and visibility among SC members (Roberta Pereira et al. 2014; Brandon-Jones et al. 2014). Other thing to note is how the globality of the firm also has an enormous influence on the complexity, as more global SC creates more complex SC on default. In addition, as mentioned earlier, on this evaluation, complexity originating from the product designs is not considered at all. The complexity ratings of the four firms are very much in line with these mentioned assumptions. Large firms with global and big SC, the firms B and C, got lower ratings in complexity. The firms A and D have more local SC and are less complex, and they also got better ratings in complexity.

The firm D is the most different from others, and it is possibly the biggest reason it has the most different ratings. This means that it cannot be fairly said that the firm D handles their SC worse than other firms, as there are multiple other reasons for their lower rating. Metal industry probably has naturally much less flexibility in processes and production compared to electronics industries. For the firm D, lower flexibility, agility, and velocity compared to other firms can be seen from their passiveness during the pandemic. However, on especially firms A and B, most actions they took were related to communication with suppliers or creating of emergency stocks. These would not be relevant actions for the firm D in their situation.

5. DISCUSSION

In this chapter, first, the results of each firm are analysed one by one. This includes comparing the findings to the framework, which was constructed in the chapter 3. The research questions 1 and 2 of this thesis will be answered in the chapter 5.1, while the research question 3 will be answered in the chapter 5.2. Last, there is a reliability and validity analysis in the chapter 5.3.

5.1 Methods for preparing to crises and disruptions

The firm A has a good score in the rating system in the previous chapter, as it has much over 50% on the relative total score. This is in line with the effects of the pandemic in the firm, as they had some drop in sales, but it was not a threat for the business continuity. Drop in the demand is mostly outside of their own control, so for that, the help from high resilience would be limited. The lack of some materials in the beginning of the pandemic was directly because of the pandemic, and for that, their own actions were used to mitigate the effects and remove the disruption or lessen its seriousness.

For the firm A, the main deficiency in their SCRES is related to flexibility, especially the lack of redundancy in supplier options. Based on the earlier findings from the literature and observations from the interview, the key areas for increasing redundancy and flexibility for the firm A could improving collaboration, supply chain design, and risk management. This recommendation is based on the paper by Jüttner et al. (2011), who found out the positive effects of collaboration and risk sharing on flexibility. Part of improving supply chain design and risk management in their situation should be finding new possible supplier options if the risks from the lack of multiple options are too significant. The beneficial effects of using multiple suppliers are found in the paper by Chowdhury and Mohammead (2017), as they conclude it decreases vulnerability in most cases.

It is also notable how the ratings for the firm A and the framework presented on picture 5 and table 4 are matching together very well. The firm A has not the best score in flexibility and velocity, but in agility they have the best score. Requirements for flexibility and velocity are visibility, collaboration, risk management, company's knowledge, and

supply chain design. For the firm A, one of these is not rated, one of these is rated “3”, but other three of them are rated only as “2”, same as flexibility and velocity. This would suggest, that improving flexibility by improving other elements will also lead to improved velocity in the firm A. And similarly, agility in the firm A is excellent, but the requirement for it is the whole group of working together, which seems to be in a good state in the firm A. This approach of increasing elements and SCRES by improving other elements is based on the papers by Wieland et al. (2013) and Soni et al. (2014), which both recognize the interconnectivity between the elements of SCRES.

Regardless of the firm A having a rating of “3” in both visibility and information sharing, it alone is not enough for lifting the rating of risk management also to the same rating, based on the evaluation done in the previous chapter. For this, the reason might be that risk management is less dependent on other elements and requires more attention and planning directly on its own. Information sharing and visibility might be required for good risk management in terms of SCRES, but they alone do not guarantee it. In the scientific literature, Jain et al. (2017) explain that visibility and information sharing need to be for the right information for it to affect SC risks. Risk management for the benefit of SCRES would be the best in the form of “supply chain continuity management” (Christopher and Peck 2004). Risk management is so vast a subject that it would be too simplified to make conclusions on it based on only visibility and information sharing.

The firm B has very similar scores together with the firm A. On relative score, they are almost identical. On absolute score, the firm A has noticeably better score, but it is not a fair comparison, as some elements for the firm B are not rated. Both firms also are similar in other ways. Both are in the same industrial field but focus on a different type of products. Their sizes are not very different, with B being bigger, and both are operating globally. There are some important differences between them. The firm A has their key partners and supply chains more focused in smaller region, while the firm B has suppliers and partners all over the world more globally. In addition, the firm B does its manufacturing in Finland, while the firm A has multiple manufacturing plants around the world.

For the firm B, the effects of the pandemic were originally almost completely insignificant. Part of this is surely because of their own fast actions and planning. The direct effects of the pandemic did not harm their business significantly. Later, the pandemic caused indirect effects, which caused a large drop in their demand, but for this, the firm B itself had very little control over. For this COVID-19 pandemic, the SCRES in the firm B was clearly not the limiting factor for their problems. For this reason, it is very difficult to say if the score given to the firm B represents their state of SCRES accurately or not.

For the firm B, the biggest impact from the pandemic was the drop in demand. This is rather little connected to SCRES. For SCRES in the firm B, their deficiencies seem to be flexibility, and possibly supply chain design, and visibility, together with collaboration. For these, there is rather little information available, so the reliability is very low. It could be possible that the firm B would receive “3” rating for some of these elements if there would be more material available to support the higher rating.

When comparing the relations between ratings the firm B received and the framework from the chapter 3 and the picture 5, we can try to analyse the ratings further. Velocity and agility received the best rating. By looking backwards from them, on which other elements improve those two, perhaps the firm B has excellent capabilities in working together, and in supply chain design. From those, SC design and collaboration were not rated for the firm B because of the lack of reliable source material, and only one out of three other elements in working together received the same best rating as velocity and agility. This could be an indicator that the firm B has also collaboration and SC design on excellent state, worth of rating “3”. This conclusion, however, is not possible to make from this material alone, as there are other components affecting velocity and agility, and there can be some amount of mismatch and unreliability between the theoretical framework and the way the ratings are given to the firms in this thesis. On the other hand, flexibility rating is matching between ratings and the framework, as flexibility and all its component elements received the same rating of “2” or were not rated.

Another interesting detail to point out about the ratings of the firm B is how arguably the most important elements for SCRES, which are the group of “Speed and adaptability”, received together slightly better ratings than those in the firm A. Those elements are more affected by other elements than any elements in other groups are. The importance of the elements in this group is supported in the literature, as in their paper, Wieland et al. (2013) argue that SCRES is only made from elements of that group. Carvalho et al. (2011) have similar findings. Also, in the systematic literature review in this thesis, as seen in the table in appendix C, especially flexibility, redundancy, and agility are very well recognized elements of SCRES. The difference between those elements in the firm A and B are small, so it does not mean there is some mistake or conflict. But also, this detail would show that the elements which were not rated in the firm B, might be in the reality worth of rating “3”, or that some other elements in the firm B were rated too low, or in the firm A too high. Again, this is only a very weak indicator of conflict between the ratings, or ratings and the framework, but it is worth noting.

Based on this material, the firm C is clearly the most resilient out of the four firms. Its rating on this scale is nearly perfect. It needs to be said, however, that this ratings

scale is made for this thesis, and it would not be possible to make very detailed scale, because in this thesis, it is not possible to see and investigate small details about the firms, and all evaluations must be done with rather little amount of material. In addition, there are many other sources of inaccuracy in the process of rating elements. So, having almost perfect rating in this scale does not mean SCRES in the firm C is perfect.

The firm C seemed to do the most work and planning when battling the effects of the COVID-19 pandemic. The pandemic had many effects on the firm C, especially on demand and as delays. The firm C took necessary actions to lessen the effects, and the pandemic caused many changes in their planning and preparation processes. For the firm C, in the ratings of elements, there is very little to be discussed. As the firm C has the best rating in all except complexity, there are not really many possibilities to compare the effects between the elements with the framework form the chapter 3. Some amount of complexity is a natural result of global and large supply networks, as there are many players and flows of goods and information in the network (Roberta Pereira et al. 2014).

One thing to point out is how the firm C does not have any combination of ratings, which contradicts the framework in the picture 5 and the table 4. There are no elements with lower rating, which lead to another element with higher rating. Complexity itself affects directly only SC design, but they both affect each other, and SC design has many other dimensions to it as well and is not dependent only on the level of complexity (Chowdhury and Mohammead 2017). The reliability of these results is a whole another subject, which is discussed later.

The firm C is the biggest and most global out of the four firms. Its industry is in the same category as firms A and B, so that is not the reason for the differences between them regarding their SCRES. The size could have some effect on resilience. Being a large and very global firm, maybe having high SCRES is required to be successful. Perhaps it is one requirement to grow so large and global, and growing firms with low SCRES will at some point face big difficulties, especially if it has competitors with betters SCRES. Large firms also have much more resources available to use. The result from this is that they can have teams and personnel with more specific skills and responsibilities. Smaller firms do not have the same resources for having a team responsible for crisis response and risk management. This might be connected to the argument in the literature that financial strength is one element of SCRES (Roberta Pereira et al. 2014; Chowdhury and Mohammead 2017). Larger firms can also have more personnel allocated for management, planning, and control, and they have more recourses for make plans and preparations, and for creating redundancy. One additional as-

pect is that large firms have more negotiating power. This itself makes it easier to create flexibility, redundancy, and control, as their suppliers and partners can be very dependent on them.

The firm D is the most different out of the four firms in this thesis. It also has clearly the lowest score in rating of the elements. Interestingly, the firm D suffered relatively moderate amounts in the pandemic, but this is apparently because of other factors. Their new order rates were affected a lot, but like with other firms, they have very little control over this, even with good SCRES. The reason this did not harm the firm D a lot in some factories was because before the pandemic, their situation was already imperfect with long production backlog.

As the firm D is the least globalised, and has their SC largely inside their own organisation, it is understandable how SCRES during a global pandemic might have less importance for them. Some signs of what effects their low SCRES might have are the problems mentioned in the interview, how earlier layoffs were creating visible problems later. It could be possible that the layoffs would have been less harmful, if they would have better visibility, collaboration, agility, and flexibility, as they might use layoffs in a more optimal way and reacted faster to changing situations.

From these four firms, the firm D took the least number of actions to fight the pandemic with planning and controlling. Based on this, and the effects of pandemic, it seems the ratings of elements are reasonable. When looking the ratings closer, in the group of “speed and adaptability”, all 3 elements have the lowest ratings. If the SCRES in the firm D is low, it makes sense that these elements have low ratings, as they on many parts result from other elements. If examined one by one, in agility, the improving elements are in a group of “working together”. In the firm D, elements in that group are moderate. For flexibility, the ratings in the firm D in the elements required for improving flexibility are also similarly moderate. For velocity, the ratings for needed elements in the firm D are slightly better overall, but still not great. With that, there is no mismatch between the framework from the chapter 3 and findings based on the interview.

On the firm D, it is noteworthy to point out how elements in the group of “preparedness and structural strengths” seem to be rather good, with one being “3”, one “2”, and one not rated. The reason for this is most likely based on the organisation structure and its local presence. Another explanation might be the difficulty of rating these elements and, as a result, low reliability of the ratings.

The elements in the group of Working together in the firm D have overall moderate ratings. One big reason for the rating being this low might be because of the criteria used

for the rating. The rating does not consider that well things happening inside the organisation as being part of “Working together”. Similarly, this same problem was present in how the interview was structured to focus more on other partners and suppliers, rather than a situation where the SC is very integrated within the organisation. In the interview, also the aspects of working together within the organisation were discussed, but there was rather small amount of detailed information about it.

As mentioned earlier, the firm D is the most different one out of these four firms. It operates in an entirely different industry, and is the least globalised of them, and it has much more vertically integrated SC in the organisation than any other of the firms. All these factors are very likely to have an enormous influence on their level of SCRES. Less global firms arguably have less need for high SCRES. This argument is supported by the literature, as it is said that global sourcing and long supply chains can increase complexity of the SC and risks for disruptions (Colicchia et al. 2010; Gunasekaran et al. 2015). Operating in metal industry might not directly be a reason for lower SCRES, but as in metal industry materials and components and products are typically very heavy and costly to transport, it makes sense that they are not that typically transported very far globally from the origin, and this might have some indirect effects on SCRES.

In all these four firms there might be many reasons for their current state of SCRES, both positive and negative. It is possible they do not have the required skills and knowledge for building higher SCRES. Could be that they do not have the interest and support from management for it and want rather do things stable way as always before. Maybe for their perspective, it is not within their control, as it is so reliant on other players in the SC.

Overall, the findings in the theory chapter seem to hold true based on the findings from the analysation of the interviews. One of the key points to take is how elements of SCRES in their groups of “working together”, “preparedness and structural strengths”, and “speed and adaptability” are all affecting each other. In general, elements in the group of “working together” will improve the elements in other groups, and elements in the group of “preparedness and structural strengths” will improve flexibility and velocity. This and the findings in this chapter can be used to answer the research questions 1 and 2. For research question 1, *“How can businesses, countries, industries, and societies be the best prepared for crises and disruptions, such as the global pandemic?”*, the answer would be having good flexibility and velocity, good state of working together with SC partners, good knowledge of possible risks and vulnerabilities, and having a big enough supply of critical components.

For the research question 2, *"In which ways can businesses prepare for disruptions the most efficiently, offering good resilience, without being too expensive to be financially suitable?",* the answer depends more on the current state of the firm. In general, it seems that if the state of supply chain resilience is not good, meaning having less than 50% in the relative total score used in this thesis in the table 17, one of the most important actions for increasing SCRES would be investing in the elements in the group of "working together". Findings from the literature and the interviews clearly point that working together with the SC partners is critical for building SCRES. When the resilience is already good, the next goal in increasing resilience would be investing on flexibility and velocity, which could be done by increasing elements in the group of "preparedness and structural strengths". Details about increasing the state of each element are explained in the chapter 3.4. The cost-effectiveness of these options depends highly on the state of the firm, which means it would need to be analysed further case-by-case in each firm.

5.2 Vulnerability to disruptions

The last research question was *"What type of businesses are the most vulnerable to crises and disruptions, and have the biggest needs for resilience, plans and preparations?".* From the literature, one finding to this research question is that firms with production in small geographical area are more vulnerable to disruptions in their own facilities in that area (Chowdhury and Mohammead 2017). The empirical part of the thesis gave information about this, but with relatively low reliability as the sample size is small. The findings show how in all the firms interviewed in this thesis; the size of the firm does not directly correlate with the level of the SCRES. It needs to be pointed out, however, that all the interviewed firms are large firms, and no small or medium-sized firms with less than 250 employees were part of this research. To some extent, very large firms, such as the firm C in this thesis, might be naturally more resilient because of their size. As it is only one firm in this sample, this conclusion cannot be made reliably, and it cannot be proven that the good SCRES of the firm C results from its size. The industrial field and the level of globalisation of the firm, on the other hand, might have a larger impact on the SCRES. Out of the 4 firms in this thesis, all 3 in the electronic & electronic machinery industry had good SCRES, while the only one in metal industry had much lower SCRES. Also, the firm D was the least globalised out of the four firms. From these findings, it is possible to make a conclusion that more global firms have more need for supply chain resilience, whereas less global firms have less need for it.

Another observation for answering the research question 3 is that firms with narrow product portfolio might have higher need for higher SCRES, as they are more vulnerable to demand-side disruption. This observation is based on the interviews of firms B and D, as they both had drop in their demand: the firm B had significant drop in the demand for their products, while the firm D had less critical but still significant drop in the demand. Both firms have relatively narrow product portfolio, but its role on the demand drop is not entirely clear. In this thesis, there is no answer to how big impact the product portfolio has to the vulnerability.

Last, firms with high dependency on critical suppliers are vulnerable to disruptions in SC (Christopher and Peck 2004; Roberta Pereira et al. 2014). This finding was confirmed by interviews of the firms A, B and C, as they all mentioned single source components being source of vulnerability during the pandemic. The firm C mentioned they were actively trying to stay in a situation where they do not have any components with single source without other supplier options, for the purpose of decreasing vulnerability.

5.3 Reliability and validity analysis

In this chapter, the reliability and validity of the results in this thesis are analysed. Reliability refers to “replication and consistency”, meaning that the same results should be achieved by replicating the research (Saunders et al. 2016, p 202). Validity refers to accuracy of results and the generalisability of the findings (Saunders et al. 2016, p 202). According to Saunders et al. (2016), there are four threats to the reliability of a research: (1) participant error, (2) participant bias, (3) researcher error, and (4) researcher bias.

The first threat, participant error, includes any factors that might alter the way the participant performs (Saunders et al. 2016, p 203). In this research, this threat exists, but can be considered small. The interviews from the firms A and B were early in the day, before noon, but the interview from the firm D was late in the day, probably one of the last things of the workday. However, it did not have any noticeable effects on the pace or quality of the interview or the answers. The interviewee from the firm C appeared to be slightly busy, as the interview had to be delayed about 30 minutes, but it did not either have any noticeable effects and the interviewee paid attention to the interview and the answers.

The second threat to the reliability is participant bias. This includes factors which might cause false responses, for example because of a fear of being judged by their answer (Saunders et al. 2016, p 203). In this thesis, this threat might be more significant than

the first threat. The interviews were anonymous and done with only one person present. However, it is possible that some people want to appear naturally good even anonymous. It can be as simple as giving an uncertain answer when the reality is certain, but the real answer might make the firm, or the person, look bad. This could lead to a situation where the reality of simple “no” turns into an answer of “maybe” and is analysed as a weak indicator of “yes”. These depend some amount on the personality of the interviewee. It is possible that none of the interviewees in this thesis gave overly optimistic answers. In this thesis, it must be accepted that all these could happen, and there is very little that can be done for controlling them in this scale, without conducting larger interview research. Furthermore, the subjectivity of the interviewees and their answers is one aspect included in the participant bias. In a larger research, it could have been possible to choose more than one person from each firm to lower the effects of participant bias.

The third threat for reliability, researcher error, includes factors which affects researcher’s interpretation (Saunders et al. 2016, p 203). In this thesis, researcher error might come from the interpretation of both scientific literature and the answers from the interviews. In the chapter 3, there are in total 16 elements of SCRES discovered and discussed in this thesis. Only in very few source papers there are all the same elements mentioned. In most papers, the number of elements discovered or mentioned is much smaller. If multiple different papers are used as a source for understanding and introducing the element in this thesis, the original meaning can be slightly distorted from one or more of the papers. Same might be true for building the framework of resilience in the chapter 3. This alone is not problematic, but it could create problems with the validity of the framework if the definitions used in the theory chapter are not consistent throughout the whole thesis.

The entire process of rating the elements for each firm is slightly subjective, as there are not written criteria on each element for each rating. There is also some amount of uncertainty in how the answers are interpreted, which might cause different firms getting different rating for wrong reasons. In addition, related to the rating of “not rated” there is some amount of unreliability. As the material from interviews is limited, all ratings are based on a relatively small amount of information. Because of this, there needs to be set a limit on what is too little information for giving a rating. If the limit is too low, some ratings might be very unreliable with very little information backing them. If the limit is too high, there are too many ratings as “not rated”, which distorts the overall ratings. This aspect can be considered a small source of unreliability, as there are only few ratings with score “not rated”.

The last threat for reliability is researchers bias, which includes factors that could affect the researcher's recording of responses (Saunders et al. 2016, p 203). Analysing this source of unreliability objectively is challenging. This threat to reliability was minimised by avoiding loaded questions and using neutral tone in the questions and in the interview situation. Furthermore, the analysation of the answers was done as systematically and consistently as possible, so that the subjectivity would be minimized.

Research validity means that the measures in the research are measuring what they are intended to, and that the results and findings are correct and generalisable (Saunders et al. 2016, p 202). Related to the measurement of intended information, possible source of invalidity comes from building the interview questions so that they represent accurately the goal of the research. This source of invalidity was tried to keep minimised by planning the questions carefully based on the framework of resilience and the research questions.

For validity related to generalisability in this thesis, the largest threat is possibly the small sample size of the empirical material. The material in the empirical part was collected by interviews from only four firms with one interview per firm. This way much of the material used in the analysis are based on only one source, relying exclusively on the perspective of one person per firm, which naturally results in lower reliability. In addition, three out of four firms are from the same general industrial field," Industrial, Electric & Electronic Machinery", and only one from another field. There are many industrial fields with no representation at all in this thesis, and for those industries, the results are less valid. However, the results from this research are reasonably valid in firms and organisations which are similar to the firms interviewed in this thesis and are in similar situation.

6. CONCLUSIONS

In this chapter, the conclusions of the research are presented. First, the contributions of this research to the scientific literature are discussed in the chapter 6.1. The chapter also includes a comparison between the research questions of this thesis and the findings. The chapter 6.2 has targeted recommendations to the interviewed for developing supply chain resilience. The recommendations are also generalised for using in other firms in similar situations as the interviewed firms. In the chapter 6.3, future research possibilities are identified and explained, based on the findings and observations done in this thesis and on identified gaps in the literature on supply chain resilience.

6.1 Contributions to the literature

The main goal of this thesis was: "*analysing the role of supply chain resilience in preparing and reacting to disruptions during the COVID-19 pandemic and finding ways to improve the resilience*". The material in the chapter 3 introduced the framework for supply chain resilience and its elements, and how to improve those elements. The connections between each element and groups were also investigated. The results from the analysis of the interviews support these findings too, and no contradictions were found. This information does not directly answer the question of how to improve resilience efficiently, since it depends on the current situation of the organisation. As an example, from the four firms interviewed in this thesis, the firm D would not most likely gain benefits from creating redundancy in a form of emergency stock. The firms A and B arguably would benefit from it greatly, and they both did increase and create emergency stocks during the pandemic. Overall, the material in this thesis can be used as a helping tool for improving SCRES, but it requires further analysis case by case, instead of automatically offering straight answers for all situations, especially when also considering the cost-effectiveness of the solutions.

One important contribution of this research to the supply chain resilience literature is the finding about building resilience in different situations. In this thesis, it was found that for firms and organisations with relatively low supply chain resilience, it is the most important to first invest in increasing the state of the elements in the group of "working together". Furthermore, firms and organisations which already have the elements in the

group of “working together” in a good state are better off investing in the elements in the group of “preparedness and structural strengths” for increasing the flexibility and the velocity.

One part of the goals of this thesis was to find out what role the supply chain resilience has in crisis situations. For this goal, some information was gained from the interviews, but as the sample is very limited, these findings cannot be used to represent all Finnish manufacturing industries or broader scope reliably. Based on this limited material, in Finnish electronic & electronic machinery industry with large company size and globally operating businesses, the SCRES is in a fit state, and it played a vital role in lessening the negative effects of the COVID-19 pandemic. The interviews suggested it was very important for the firms A, B and C that they took fast actions and preparations at the early signs of possible future disruptions. Furthermore, if we look the effects of the pandemic in each firm and compare that to the actions they took and the ratings which were given in the chapter 4, it can be seen how the firms with better ratings took more actions to control the situation, and thus were experiencing fewer disruptions caused by the pandemic. The firm B is an exception to this, but their only bad disruption, the drop in the demand, was largely out of their own control, even if they would have done everything perfectly. However, it cannot be seen what the situation would be if for example the firm A or C would have low SCRES. In this research, only the current situation can be seen, and only at one timeframe. There is no way to completely prove their current situation results from their actions, as there is no way to see their situation if they had taken other actions, or no actions at all.

The main contributions of this research to the supply chain, and supply chain resilience literature are the findings about what actions did the interviewed firms took to lessen the effects of the pandemic. This information can be used to gain understanding about supply chain resilience, and how it can be increased during global pandemic, and what actions can be taken to be better prepared to similar disruptions before they occur. In the empirical part of the thesis the reactions to the COVID-19 pandemic in the firms were analysed. The helpful actions in the interviewed firms during the pandemic can be summarised as closer collaboration and communication, increased preparedness to act fast, and increased emergency stock levels for critical components. Perhaps these same actions can increase resilience to disruptions during a pandemic in other firms too, and in the theory chapter of this thesis, they are all recognized as being part of the SCRES.

The final finding of this thesis was information about which firms and organisations are the most vulnerable to disruptions, and therefore would need SCRES the most. For

these findings, the contributions to the literature are smaller, as most of the findings were already present in the previous literature, and this thesis confirmed those findings. In this thesis and previous literature, it was observed that the firm's production being concentrated in a small geographical area increases vulnerability to local disruption. At the same time, very global firms with supply chain and presence in many locations are vulnerable to disruptions in multiple locations, which can increase the probability to disruptions. Being highly dependant on single source for any critical component or material also increases vulnerability to disruptions. Last, the firm B in the interviews showed that firms with relatively narrow product portfolio might be more vulnerable to demand-side disruptions. This last finding is, however, with low validity, as it is based only on one observation in one firm.

6.2 Managerial recommendations

Based on the findings in this thesis, it is possible to give some general targeted guidance for improving SCRES for each of the firms. These recommendations are also relevant for any firms in similar situations. For the firm A, the recommendations for improvement are focused on flexibility and especially redundancy. More supplier options would lower the vulnerability for disruptions with suppliers' and additionally decrease dependency on any specific supplier. Together with this, supply chain design and risk management should be systematically evaluated and improved if some vulnerabilities are found. These recommendations apply to also other firms, which have good supply chain resilience but do not have multiple supplier options with critical components and materials.

For the firm B, it is more difficult to give direct areas for improvement. In theory, diversification of their product portfolio could give more resilience to changes in demand, but this might create additional problems and be outside of their current business strategy. One option for improvement which they could analyse further is investing in manufacturing outside of Finland. This way they would have additional production facility, which alone would change the structure of the supply chain some amount compared to the current situation. It also would decrease their total vulnerability for localised disruptions in their current manufacturing facility. The cost-effectiveness of this option is impossible to evaluate with the available material, and it should be carefully analysed before making further plans. This same recommendation could be given to any firms with global presence, which has manufacturing in only one location.

For the firm C, based on this material, none of the areas of SCRES are clearly their weakness. For this reason, it is not possible to give any suggestions for improvement

for them. Continuous monitoring and improvement can always be recommended, and special attention should be paid on SC complexity. This recommendation applies to all firms which do not have clear weaknesses in their supply chain resilience.

For the firm D, many of the areas of improvements might be very limited because of their company structure. First, closer collaboration with customers might be helpful for them, as it might help to avoid situations where customer stops taking deliveries for some time without proper warning in advance. It would ideally increase planning together with the customers, instead of doing business with purely transactional basis. This could be as simple as sharing sales and manufacturing forecast information. Second, the planning inside the organisation could be one focus of improvement for the firm D. For this, the information available is not enough to see their actual situation reliably enough, which also makes this suggestion significantly less reliable. They should, however, have all parts of their internal supply chain included in their planning and decision making. For example, with good and timely feedback about the need for material supply, they could have avoided problems with too long layoffs disrupting the production further in supply chain.

The third suggestion for the firm D would be to analyse the need and cost-effectiveness of some redundancy, for example larger material storage, which would create a buffer for smaller disruptions. In the interview, it was said how the long internal SC has very often some problems at some location of the chain, which creates delays also in other parts of the SC. It requires further analysis on the costs, benefits, and requirements, but in some situations, especially in volatile conditions, it would be beneficial to have redundancy in form of safety stock for materials. This differs from emergency stock, which is used for more extreme disruptions. Redundancy stock could be very difficult and costly to do in practise if the materials are very customised, but with very standardised and similar materials, it would be more suitable option. The last suggestion for the firm D is to set a goal of continuous improvement of their agility, meaning increasing their reaction speed for changes. They could examine if they can improve reaction speed to changes in demand easily. And even minor improvements in the speed of decision-making process could improve agility. For this suggestion, it needs to be noted how the nature of their industry might make it more difficult to increase agility than in many other industries.

These same recommendations as for the firm D could be given to any firm with lower levels of supply chain resilience. As mentioned earlier, firms with less supply chain resilience should focus more on the elements in the group of “working together”.

For all firms interviewed in this thesis, it would be beneficial to develop tools and methods for actively monitoring and improving SCRES. This way they could consciously pay attention to SCRES, instead of it being only done when it is already needed, or as an additional workload. Ideally, this would allow them to spot if the SCRES or any specific element is not in a fit state, monitor possible changes, and plan ways to improve each element and SCRES. This is recommended for all firms which would benefit for having high supply chain resilience, especially very globally operating firms, and firms with large supply network.

In general, for all globally operating firms there are some areas related to SCRES which should be investigated and evaluated, and possibly improved if there is a need for it. Most times, the possibility to use of multi-sourcing with at least the most critical and vulnerable components is important for flexibility, and thus also for SCRES. Communication and collaboration with important suppliers and customers are other areas of SCRES which clearly have a big impact on SCRES while requiring relatively small investments, based on the findings in this thesis, and should therefore always be paid careful attention to. Last, also risk management plays a critical role in SCRES and can easily be improved with proper planning. As learned from the interviews in this thesis, risk evaluation is often done in businesses, but it seems to rarely include specifically the supply chain perspective in more detail. Related to SCRES, risk management should include detecting sources of vulnerability in the supply chain, including the supply chain design itself, and making action plans for various disruptions.

6.3 Future research

As the data used in the empirical research in this thesis is very limited and narrow, for the future research, one simple direction would be to have a larger sample size on relatively similar topic. The sample could be larger in total and more diverse, or it could focus on just one or few specific industries. One direction would be to investigate more closely the relations between the firm size and SCRES, especially since in this thesis, no small or middle-sized firms were included at all. These ideas of possible future research are mostly doing very similar research as this thesis, but on a larger scale. In all these, it would benefit the research greatly, if there would be either some access to the firm's information, or possibility to do multiple interviews with each firm, as in this thesis the lack of material and sample size were possibly the biggest limiting factors as sources of unreliability and inaccuracy.

Another direction for additional research would be focusing on specific variables and their roles in resilience. The focus could be on the firm size, industrial field, small num-

ber of specific elements, or one element group. The goal in this kind of approach would be to find out what effects the chosen variables have on SCRES and to do throughout evaluation related to them. This would be understandably difficult to do, as it would be a challenge to control for other than the chosen researched variables.

Future research could also focus on longer timeframe and examine the differences and development in a longitudinal study. In this thesis that was one limiting factor, as the interviews were done on only one time point. This could be done in few different ways. By repeating interviews, surveys, or other observations without intervening is one way to examine the changes. Another possibility is to intervene on purpose after the first data gathering, for example by working together with the firm to improve SCRES or give information or training about SCRES. This way, by comparing the differences to earlier results, it could be possible to get clear information about the effectiveness of SCRES improvements, and possibly even more specific information about which actions are the most useful for improving SCRES in different situations. This could be especially useful for learning the role and importance of specific elements of SCRES better.

In future research, if the focus is on measuring the state of resilience or elements, it would be advisable to develop a way to measure and calculate SCRES or elements, as was shortly explained in the chapter 3.6. In this thesis, that would not have been possible to use because of limited resources, but in larger research, especially if that is the focus, it would be beneficial and strongly advised. Developing a measurement system for SCRES could also be on its own the entire focus of the research. That would benefit the scientific research around the subject of SCRES, as currently the ways to measure reliably SCRES, or even specific elements, are rather limited.

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APPENDIX A: ARTICLES AFTER THE FIRST ROUND OF REFINING IN THE SYSTEMATIC LITERATURE REVIEW

Author
Fiksel, Joseph (2003) Christopher & Peck (2004) Li et al. (2006) Wagner et al. (2006) Datta et al. (2007)
Bakshi et al. (2009) Mitra et al. (2009) Colicchia et al. (2010) Bhamra et al. (2011) Carvalho et al. (2011)
Jüttner and Maklan (2011) Zhao et al. (2011) Carvalho et al. (2012) Gligor et al. (2012) Spiegler et al. (2012)
Popa, Virgil (2013) Wieland et al. (2013) Brandon-Jones et al. (2014) Pereira et al. (2014) Soni et al. (2014)
Wang et al. (2016) Brown et al. (2015) Gunasekaran et al. (2015) Tukamuhabwa et al. (2015) Kamalahmadi et al. (2016)
Lee et al. (2016) Mandal et al. (2016) Brusset & Teller (2017) Chowdgury & Quaddus (2017) Jain et al. (2017)
Namdar et al. (2017) Adobor (2018) Blackhurst et al. (2018) Saenz et al. (2018) Sawyerr et al. (2019)
Ivanov et al. (2020) Piera et a. (2020)

APPENDIX B: INTERVIEW MATERIAL

Resilience of manufacturing supply chains during the covid-19 pandemic

This interview is part of Master's Thesis research at Tampere University. The purpose of research is to increase understanding of the effects of Covid-19 pandemic on manufacturing industries, supply chains, and the state and role of resilience in the firms. The collected information will be used, with the support of theoretical material, to gain knowledge about the role of supply chain resilience in disruption situations, to increase resilience in organizations, and to learn which actions are helpful for businesses.

Individual answers, companies, or interviewees will not be visible or recognizable in the thesis, or any material with public access. The material from this interview will be used as an anonymized source in the empirical part of the thesis.

The interviews will be carried out during October 2020 in Teams meetings by Heikki Turja who is doing this Master's Thesis. One hour needs to be reserved for the interview. The interview will be recorded for documentation purposes if the interviewee will give permission for recording. Interview notes will be prepared and sent to the interviewee for review and further comments. The interview recording will be deleted after the interview notes have been prepared and will not be used for any other purposes.

In this study resilience is defined using the following definition by Tukamuhabwa et al. (2015):

"*The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations – ideally, a better state than prior to the disruption.*"

Supply chain resilience consists of a high number of components that we have grouped in this study in three broad categories:

- Working together,
- speed and adaptability, and
- preparedness and structural strengths.

The following interview questions are grouped according to these categories. First, we start with a couple of introduction questions.

- What is your title and responsibility area in the firm?

- Please describe in general terms how the Covid-19 pandemic has affected your firm and its supply chains? E.g., what have been the effects on demand, supply, operations and/or distribution?
- What have been the most important actions at management and planning in the firm caused by the pandemic?
- Is resilience a known and used term and concept in your firm? If not, is there some other term that is used to mean the firm's ability to respond to unexpected disruptions and return operations back to normal performance level?

Working together with the suppliers:

- In which ways can your firm detect supply chain disruptions? For example, during the Covid-19 pandemic, which were the first signs of disruptions? Is the detection heavily reliant on others in the supply chain and information sharing?
- Please describe typical ways how your company has shared information with key supply chain partners to respond to the challenges caused by the Covid-19 pandemic?
- Can you give some practical examples of the collaboration that you have done to overcome the Covid-19 challenges with the closest supply chain partners?
- Have you detected disruptions in the supply chain deeper than the first-tier suppliers during the Covid-19 pandemic? Do you receive information about disruptions upstream in the chain directly or through your first-tier suppliers, potentially with a delay?

Speed and adaptability:

- How prepared would you describe your firm to be for making fast changes to market needs, such as radical changes in demand volumes, cancelled orders, lack of materials etc.?
- To what extent can you make changes in your firm's own production and logistics operations, e.g. in terms of flexibility in altering production volumes and making schedule changes.
- What are the principal ways of preparing your firm's key suppliers to react to sudden changes in the market needs? For example, are there many supplier options, many geographical locations where to buy from, possible to use multi-source for a single product/item, mutually agreed reserve inventory at the suppliers etc.?

- In a situation where production in one place is seriously disrupted, do you have the possibility to move the production to another location/facility, either in your own firm or supply network?

Preparedness and structural strengths:

- Was there already an action plan in place in your company for these kinds of disruptions before the pandemic started? If yes, what levels of organization did it cover, e.g. individual operations, the firm or entire supply network?
- In your experience of the present situation with the Covid-19 pandemic, what are the main sources of preparedness and strength for supply network in your industry? What is the role of geographical location of the suppliers, knowledge of the entire supply network, collaborative relationships with the suppliers, and/or daily operative practices enabling rapid changes to react to market needs and supply disruptions?

Closing question: Is there anything else that you would like to add? Do you have any comments related to this research and interview? Is there something that you would like to ask about this research and use of the interview data?

APPENDIX C: TABLE OF ELEMENTS IN PAPERS

Authors	FL	RD	VI	AG	CO	IN	IS	FS	C&C	TR	SCD	RM	CK	VE	CX	SU	Grouping
Tukamuhabwa et al. (2015)	X	X	X	X	X	X	X		X	X	X	X	X	X	X		FL, RE, CO, AG
Mandal et al. (2016)	X		X	X	X		X					X		X			CO, FL, VE, VI
Jüttner & Maklan (2011)	X	X	X	X	X		X					X		X			CO, FL, VE, VI
Carvalho et al. (2011)	X	X	X		X	X	X				X			X			FL, RE
Christopher & Peck (2004)	X	X	X	X	X		X		X		X	X	X	X	X		CO, AG, SC reengineering, SC RM
Wieland et al. (2013)	X		X	X	X		X			X	X	X					Robustness + AG
Piera et al. (2020)	X	X	X	X	X	X	X		X	X	X	X		X	X		Anticipation, resistance, recovery
Chowdgury & Quaddus (2017)	X	X	X	X	X	X	X	X			X	X	X				Proactive and reactive capability, SCD
Brusset & Teller (2017)	X		X	X	X	X	X					X	X				External, IN, FLcapabilities
Adobor (2018)	X				X		X			X		X	X				No groups + multi-level
Jain et al. (2017)	X		X	X	X		X		X	X	X	X				X	No groups
Brandon-Jones et al. (2014)	X		X	X	X		X					X		X	X		No groups
Carvalho et al. (2012)	X	X	X	X	X		X					X	X	X			No groups
Namdar et al. (2017)	X	X	X	X	X		X					X	X				No groups
Soni et al. (2014)	X		X		X		X			X	X	X				X	No groups
Gunasekaran et al. (2015)	X	X	X	X	X		X		X		X	X	X				No groups
Colicchia et al. (2010)	X	X			X						X	X					No groups
Datta et al. (2007)	X	X	X	X	X						X	X	X				No groups
Spiegler et al. (2012)	X	X			X		X		X		X	X					No groups
Pereira et al. (2014)	X	X	X	X	X	X	X	X	X	X	X	X	X		X		No groups
Wang et al. (2014)	X	X		X	X						X	X					Elements not mentioned explicitly
Zhao et al. (2011)		X									X						Elements not mentioned explicitly
Bhamra et al. (2011)	X			X													Elements not mentioned explicitly

In the table in appendix C, FL= flexibility, RD = redundancy, VI = visibility, AG = agility, CO = collaboration, IN = integration, IS = information sharing, FS = financial strength, C&C = coordination and control, TR = trust, SCD = supply chain design, RM = risk management, CK = company's knowledge, VE = velocity, CX = complexity, SU = sustainability.