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# SUPPLY CHAIN AGILITY IN SEMICONDUCTOR SHORTAGE

A multi-case study

Master's Thesis
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**Abstract of master's thesis**

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**Abstract**

The semiconductor shortage is an ongoing global crisis that has operationally and financially impacted companies' supply chains due to the supply disruptions it caused. This crisis is a wake-up call for organizations to rethink agility in supply chain. This Master's thesis aims to study how supply chain agility can be utilized in disruption management during the semiconductor shortage. The conceptual framework of the thesis provides a link between the theories of supply chain agility and supply disruption management, which acts as a guideline for companies to plan agility in managing supply disruptions caused by the semiconductor shortage or similar crises.

This research was conducted based on qualitative multi-case study through semi-structured interviews with five companies from different industries. The case companies are those operating mainly in Finland, whose product offerings are associated with semiconductors. The collected data was analyzed with thematic analysis to identify the implications of agility elements at different phases of the disruption management cycle. The conceptual framework of the thesis was developed through a synthesis of existing literature and refined based on the empirical findings.

The findings suggest that it is important to apply supply chain agility in managing supply disruptions caused by the semiconductor shortage, due to this crisis' unpredictability and severity. In pre-disruption phase, successful implementation of proactive approaches requires alertness and accessibility enabled by risk management, market sensitivity and supply chain alignment. During and after the disruption, quick and flexible responses to sudden changes in supply are enabled by utilizing existing risk management practices in addition to operational flexibility and demand management. It is also important to have recovery plan and to foster continuous learning from the crisis. Furthermore, maintaining agility throughout the whole crisis requires a culture of change, supportive top management, and strategic collaboration between supply chain partners as well as information technology capabilities.

**Keywords** supply chain agility, supply disruption management, semiconductor shortage

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# 1 INTRODUCTION

This chapter provides an introduction to the thesis background and motivation, research question, objectives and scope of the study.

## 1.1 Background and motivation

In recent decades, various worldwide crises have increased the global supply chain's vulnerability to disruptions. Supply chain disruption and risk management has become an important research topic after series of incidents that strongly disrupted the supply chains - the 2001 terrorist attack, the 2003 SARS epidemic, the 2005 Hurricane Katrina and the 2011 Japanese earthquake and tsunami (Wagner and Bode, 2008; Sáenz et al., 2018). Since 2019, the world once again faced with a destructive incident - the COVID-19 pandemic. Among the problems caused by COVID-19, the global semiconductor shortage is one whose negative impacts on the global supply chain is critical (Linton & Bindiya, 2021) as semiconductor is a core component in any electronic product needed in different industries.

Restrictions and shifting to remote work/study mode during the pandemic has significantly increased the need for consumer electronics products, causing a strong surge in semiconductor demand since 2020 (Burkacky et al., 2021). Moreover, many chip productions were disrupted due to global shutdowns, while the cost of silicon – a main component for manufacturing semiconductor - has risen significantly due to the mass production of the COVID-19 vaccines (Pizzemento, 2021). As a result, the semiconductor supply has been falling behind the global demand for chips needed in manufacturing goods. This interruption of material flows within a supply chain can be perceived as supply disruptions (Craighead et al., 2007, p. 132) or glitches (Hendricks and Singhal, 2003). Producers of products that need semiconductors as part of their components have been suffering from material sourcing difficulties and increased suppler lead time (Attinasi et al., 2021). The lack of materials limits production, delays customer deliveries and could eventually lead to a loss of sales due to cancellations and reduced customer satisfaction. Such a crisis has made it clear that companies should develop a more agile supply chain to cope with disruptions.

Supply chain agility as an approach to risk mitigation and disruption management has been studied in various academic literatures. Nevertheless, there is a need for reviewing and

re-evaluating the existing theories of supply chain agility and supply disruption management to better reflect the recent semiconductor shortage. Calvo et al. (2020) has presented agility as part of the disruption management process. However, in their framework, agility is presented only in the later phase of the disruption cycle, and detailed aspects of agility are not specified. Considering this gap, the thesis aims to develop a conceptual framework of supply chain agility in supply disruption management and explore its practical application through a multi-case study.

This study contributes a review of supply chain-oriented literature as well as provides an addition to the limited number of research on the recent semiconductor crisis at the time being. The developed framework and best practices from the study will serve as a guideline for managers to plan agility for coping with supply disruptions. As many industries rely on the supply of semiconductors, this study would provide useful insights for companies that have been suffering from negative impacts of this crisis and/or seeking to achieve supply chain agility.

## 1.2 Research question and objectives

The main objective of this thesis is to reflect the theories of supply chain agility and supply disruption management through the perspective of semiconductor shortage. Alignment of agility elements in managing supply disruptions is studied to understand how having an agile supply chain could help firms to better cope with the semiconductor shortage.

The main research question is: *How to utilize supply chain agility in supply disruption management during semiconductor shortage?*

The following sub-questions are defined to support the main research question:

*(1) What are the impacts of the semiconductor shortage on companies' performance?*

*(2) What is the role of supply chain agility in managing supply disruption?*

To answer the research questions, a literature review focusing on supply disruption management, supply chain agility and semiconductor shortage is first conducted. A conceptual framework is then developed from the literature review that describes the perspectives of supply chain agility in supply disruption management process. The practical application of the framework in the context of semiconductor shortage is explored by conducting a multi-case study. The selected case companies are operators from different industries in Finland, whose products are associated with semiconductor components and thus have been impacted by the semiconductor shortage. Qualitative data for the empirical

research will be collected through semi-structured interviews with selected representatives from the case companies.

## 1.3 Scope of the study

This study is subject to the following scopes. Firstly, the thesis aims to explore the aspects of supply chain agility in the semiconductor shortage, meaning supply disruption. Thus, other types of supply chain risk and disruption will not be focused. Secondly, supply chain resilience is addressed in this study as a target for implementing agility, therefore other conceptual aspects of resilience are not part of the scope. Thirdly, this study is focusing on the capability of the buying firm to implement supply chain agility without considering financial and resource aspects. Fourthly, as the case companies selected for the empirical study are mainly operating as tier 1 suppliers within the supply chain, the impact of the crisis on other supplier tiers further upstream is therefore beyond the scope. Last but not least, as the semiconductor shortage is still an on-going crisis at the time this these was done, the findings of this study focus on the current situations experienced by case companies.

## 1.4 Structure of the thesis

This thesis includes six chapters. The first chapter introduces the background, research question, objectives and scope of the study. The second chapter covers the review of theoretical literature on supply chain disruption, supply chain agility and semiconductor shortage. The conceptual framework built based on the literature review is presented at the end of the second chapter. The third chapter is dedicated to research methodology including descriptions of data collection and analysis approaches as well as trustworthiness and limitations of research methods. In the fourth chapter, empirical data are presented and analyzed. The fifth chapter discusses important findings derived from the collected data. The last chapter concludes the study by addressing the theoretical and managerial implications of the topic, as well as limitations of the study and suggestions for further research.

# 2 LITERATURE REVIEW

This chapter discusses Supply Disruption, Supply Chain Agility and Semiconductor Supply Chain, which serve as the main theoretical themes for this study.

The following sections will continue with concepts related to supply disruption, including the impacts of supply disruption, ripple effect and approaches to disruption management in supply chain. It is followed by concepts of supply chain agility covering its definition, dimensions, enablers, and impacts on firms' performance. The semiconductor supply chain and the semiconductor shortage are then introduced. At the end of the chapter, a conceptual framework developed from the literature review is discussed, which will serve as a foundation for the multi-case study research.

## 2.1 Supply disruption

Supply chain, a vital function in business operation, manages the goods and information flows from upstream to downstream of the supply chain (Christopher, 2011). Supply chain networks have become more complex in today's dynamic market environment, which increases companies' vulnerability to unpredicted disruptions (Pettit et al., 2010). Disruption risks can be divided into the following three categories, according to Christopher and Peck (2004): disruptions within a firm associated with internal to process and control, demand and supply-related disruptions within the supply chain, and external disruptions outside the supply chain.

As this study aims to reflect the recent semiconductor shortage, its focus will be on supply disruption happening from the upstream of the supply chain, which can be defined as a situation when the main sources of supply suddenly become unavailable or significantly delayed (Ambulkar et al., 2005; Hou et al.,2010). The most discussed supply disruptions in supply chain literature are supplier delays, supplier bankruptcy and quality of raw materials (Behdani et al., 2012)

Supply disruption risks might be attributable to many factors such as natural and man-caused disasters, logistics delays, supplier's operational inefficiency, product complexity, and poor supply chain coordination (Kumar et al., 2010; Chen et al., 2013; Chopra & Sodhi, 2014; Simchi- Levi et al., 2014; Sarker et al., 2016). The risk to supply disruption can be highly associated with the dependency on suppliers and level of agility of different souring alternatives (Chopra & Sodhi, 2014). A recent study done by Gunessee and Subramanian

(2020) also suggest that having a complex supply network with human errors and safety concerns increases the risk of global supply disruption.

The following sub-headers will discuss the impacts of supply disruption, the ripple effect, and the approaches to supply disruption management.

### 2.1.1 Impacts of supply disruption

The impacts of supply disruption on the performance of company and its supply chain can be significant, proved Parast and Subramanian (2021). Depending on the disruption's severity and the firm's resilience and recovery capabilities, supply disruptions can negatively impact the buying firm in short term and long term (Sheffi & Rice, 2005).

Immediate impacts of supply disruptions can be seen from the supply chain operation such as increasing lead time, component shortages and production disruptions. Inability to meet demand may lead to difficulties in satisfying customers and eventually sales loss, while operating costs may increase tremendously due to "expediting, premium freight, obsolete inventory, additional transactions, overtime, storage and moving, selling, and penalties paid to customer'' (Hendricks & Singhal, 2003:4). Moreover, long-term shareholder value and the company's stock performance are also negatively affected by supply disruption (ibid).

Real-life incidents have shown serious consequences of supply disruption to the global supply chains. For instance, the fire incident at Philips Electronics plant in New Mexico in 2000 resulted in supply disruption of semiconductor components to Ericsson and lead to its $200 million loss in sales (Chopra & Sodhi, 2014). Another example was the 2011 earthquake and tsunami in Japan, which caused a massive component supply disruption within the automotive and electronics industries and led Toyota to lose billions of dollars in revenue as well as its market leading position (Dolgui et al., 2018). Recent studies have shown that low frequency - high impact incidents such as COVID-19, can massively disrupt the regular supply and demand fluctuation, causing component shortage, production interruption, logistics delay and eventually losses in sales (Ivanov & Dolgui, 2020; Cai & Luo 2020).

### 2.1.2 Ripple effect

The negative consequences resulting from supply disruption may propagate further downstream to other nodes in the supply chain network, which can be referred to as Ripple effect. Dolgui et al. (2019:2) defines ripple effect as "a downstream propagation of the downscaling in demand fulfillment in the SC as a result of a severe disruption (or a series of disruptions)". For example, delay in supply of raw materials at upstream supply chain can cause delays in end customer order fulfillment at downstream.

Ripple effect's likelihood increases in complex supply chains with increasing customer requirements for delivery efficiency and speed (Ivanov, 2018). According to Dolgui et al. (2018), the propagation of disruption risks in the supply chain are typically resulted from several factors related to sourcing, inventory management, production planning and control, as shown in Figure 1.

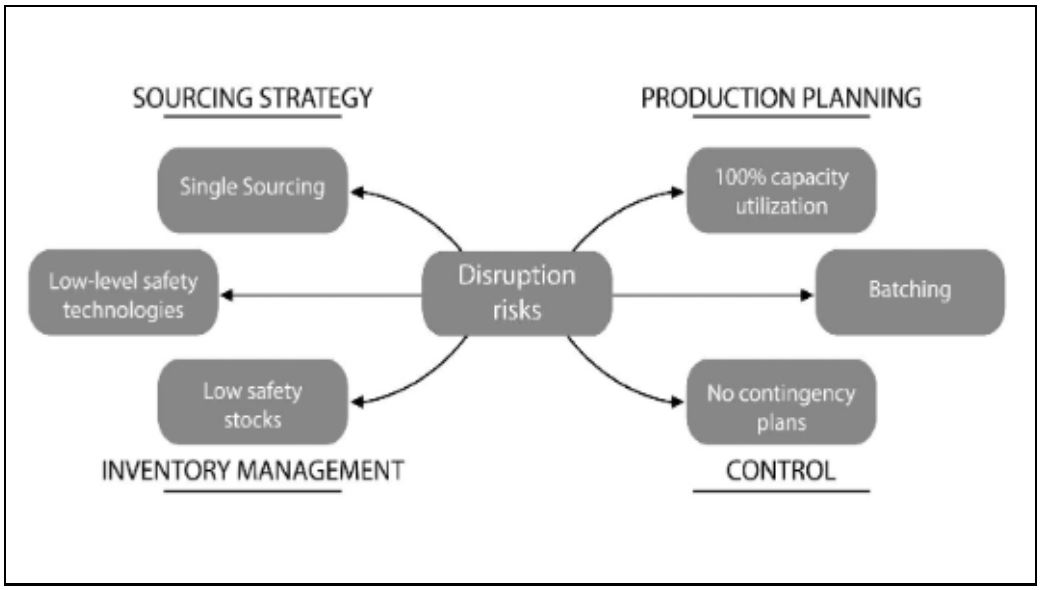


*Figure 1. Reason for ripple effect (Dolgui et al., 2018)*

The consequences worsen with each new propagation, meaning that the further the firm locates at downstream of the supply chain, the more it suffers from negative impacts of disruption (Dolgui et al., 2018). Controlling ripple effect requires the supply chain's ability to be resilience while achieving maximum performance at an acceptable redundancy costs (Ivanov & Dolgui, 2019).

### 2.1.3 Disruption management in supply chain

The research of disruption management in supply chain has gained significant attention from academicians during the past few decades. Behdani et al. (2012:8) defines supply chain disruption management as "structured and continuous process to analyze the impact of disruptions across the supply chain on predefined objectives and to handle them in their entire lifecycle".

According to Sheffi and Rice (2005), a disruption cycle includes eight stages which are associated with level of company performance overtime, as shown in Figure 2. The authors also emphasize that company performance significantly reduces once the full impact occurs, and it takes time to recover. Despite actions taken for recovery, some negative impacts can be long-lasting, for example on reputation or customer relationship.

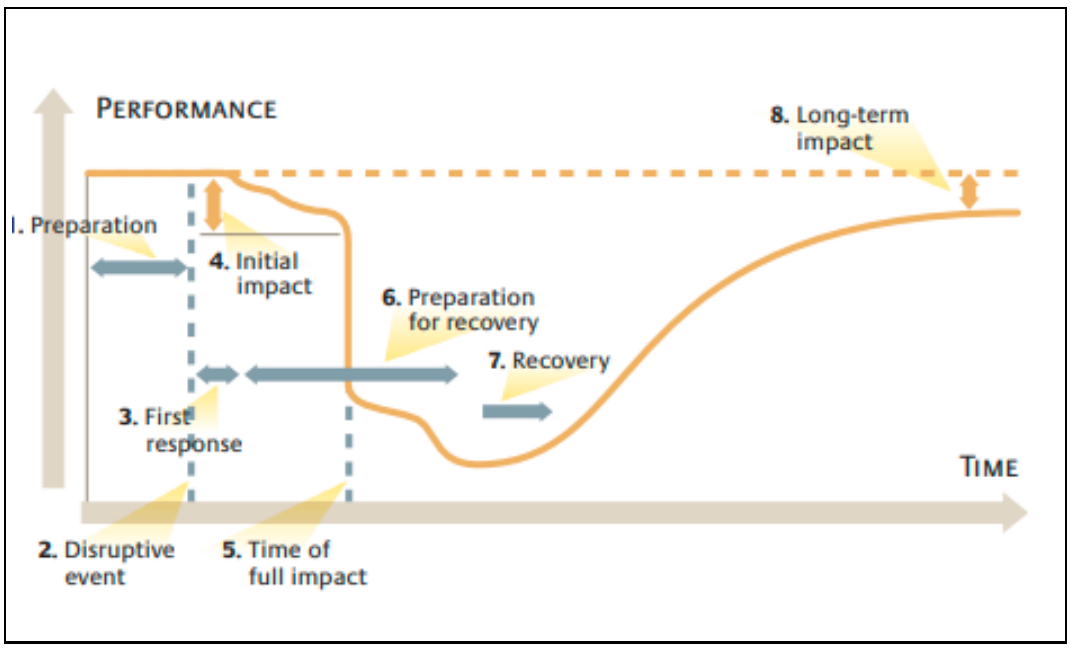


*Figure 2. Stages of disruption (Sheffi & Rice, 2005)*

In handling disruptions in supply chain, two main common approaches have been discussed in literature: the *pre-disruption (proactive)* approach which focuses on measuring the vulnerabilities to disruptions and taking precautionary measures to reduce negative impacts, and the *post-disruption (reactive)* approach which refers to reacting and adjusting processes once the disruption has occurred (Behdani et al., 2012; Hosseini et al., 2019). These approaches can be reflected from the crisis management cycle shown in figure 3, which consists of four phases: mitigation and preparedness (pre-disruption), response and recovery (post-disruption).

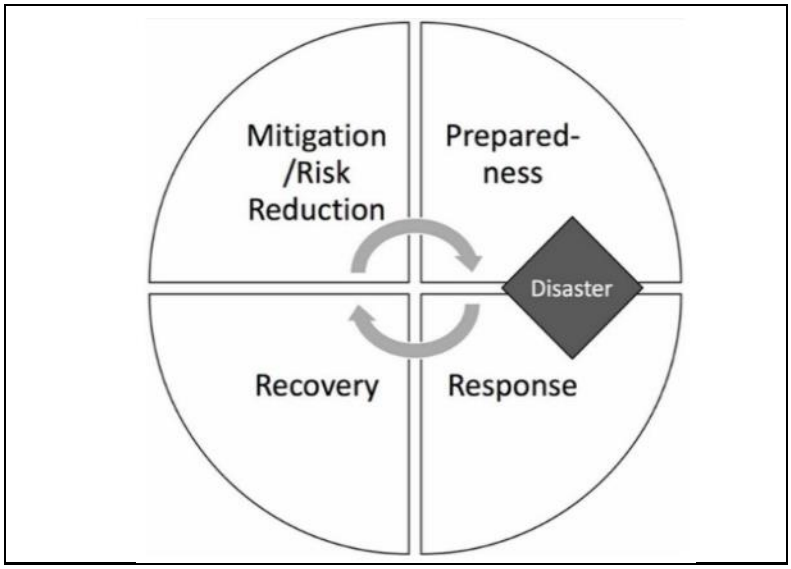


*Figure 3. Crisis management cycle (Harrison & Johnson,2016)*

**Mitigation** in disruption management is referred to the implementation of strategies that aim to reduce negative impacts in case disruptions occur. It is important for companies to identify and understand the potential risks of disruption and select the appropriate tailored mitigation strategies (Chopra & Sodhi, 2004). Approaches to mitigate supply disruption in academic literature have been focused on flexibility, redundancy, control, and cooperation strategies (Behdani et al., 2012). The mitigation strategy types, approaches and descriptions are shown in table 1.

**Preparation** phase includes short-term proactive activities to detect the disruption while organizing and allocating resources (Behdani et al., 2012; Kim & Zhao, 2021). End to end visibility is critical in this phase in order for companies to identify abnormal situations in the supply chain, which can be achieved through information sharing, usage performance monitoring and warning system (Stecke and Kumar, 2009). Chen et al. (2019) also suggests that the discovery and preparation for disruption should involve visibility to accurate information in real time, analysis of disruption profile to predict the impacts, as well as facilitate initial decision making. All activities done in mitigation and preparation phases are crucial for appropriate responses when disruption occurs.

*Table 1: Mitigation strategies in disruption management [adapted from: Chopra and Sodhi (2004), Christopher and Peck (2004), Sheffi (2005),Chopra et al. (2007), Stecke and Kumar (2009), Behdani et al., 2012)]*

| Strategy type | Approach | Description |
|---|---|---|
| Flexibility | Multi-sourcing | Switching to another supplier when one is disrupted |
| | Flexible contract | Flexible adjustment of the contract terms |
| | Product postponement | Postponement of product customization |
| | Flexible manufacturing | Shifting of production among different plants |
| | Flexible transportation | Using multiple modes of transport and working with multiple logistics providers |
| Redundancy | Buffer stock | Having extra inventory of raw materials or finished goods |
| | Backup supplier | Having secondary suppliers in addition to main supplier |
| | Overcapacity | Having excess capacity in certain processes |
| Control | Security management | Enhancing security in supply chain in terms of physical, information and freight security |
| | Demand management | Temporary change of demand pattern and shifting of customer choices to other alternatives |
| | Supplier performance | Controlling the quality of supplier performance |
| | Performance-based contracting | Applying incentive mechanism in supplier contracting |
| | Employee training | Providing employee training to increase knowledge about disruptions and response plans |
| Cooperation | Joint planning | Collaborating with suppliers to develop disruption management plans |
| | Resource and information sharing | Enabling shared resources and information between supply chain partners |

**Response** to the disruption when it happens requires real-time rapid actions in resource allocation as well as active information sharing and collaboration (Behdani et al., 2012; Kim & Zhao, 2021). The approaches planned in the mitigation phase may come into use, for example taking materials from buffer stock, ordering from backup suppliers, or using flexible transportation (Stecke and Kumar, 2009).

**Recovery** is the last phase of the disruption management cycle when actions are implemented for returning operations back to normal. Recovery capability in supply chain

is defined as “interactions of supply chain entities and corresponding coordination of supply chain resources to return the supply chain to a normal and planned level of product flow” (Braunscheidel & Suresh, 2009:136). Recovery plans focusing on stabilizing and adapting supply chain activities should be implemented in a timely manner, which help reduce long-term consequences and ensure business continuity (Ivanov et al., 2017). For short-term disruptions, Chen et al. (2021) proposed to make emergency purchase from the undisrupted supplier with increased quantity to ensure original products’ manufacturing. In case of long-term disruptions, partial change of product type should be considered, which enables the replacement of raw materials and selection of new supplier without changing main product design or manufacturing procedures (Chen et al., 2021). Furthermore, it is crucial to foster active learning from the disruptions to serve as basis for future mitigation strategy planning.

## 2.2 Supply chain agility

Surviving in turbulent and dynamic market environments requires companies to maintain agility in their supply chains (Agarwal et al., 2007). Agility is essential especially in the manufacturing industry where many activities are dependent on other partners within the supply chain (Perera et al., 2019).

The concept of supply chain agility in supply chain is closely related to supply chain resilience, which can be defined as the ability to utilize capability of supply chain entities to respond and adapt to unexpected changes, minimize the negative impacts of disruptions, and recover to normal operations (Hosseini et al., 2019). Christopher and Peck (2004) indicated that “resilience implies agility” and slow response to changes in demand and supply can make companies more vulnerable to risks. According to the literature review done by Simbizi et al. (2021), agility has been categorized by various academicians as one of the main elements of supply chain resilience.

This study focuses on agility as a driver to create a more resilient supply chain for coping with supply disruption. The following sections will introduce the theoretical definition of supply chain agility, its different drivers and dimensions as well as its implication in supply chain disruption management.

### 2.2.1 Defining agility in supply chains

Supply chain agility was first introduced by Dove (1996) as the supply chain's ability to adapt to market changes through integration and collaboration. Christopher (2000), Chirstopher & Beck (2004), Lee (2004) and Swafford et al. (2006) emphasize that supply chain agility involves the timely and flexible responsiveness to unpredictable changes in demand and supply, as well as quick recovery to normal operation.

Agility does not concern only the firm's capability but also the agility of other partners within the supply chain network (Lee, 2004). Thus, the definition of agility in supply chain was extended by Braunscheidel and Suresh (2009:126) as "capability of the firm, internally, and in conjunction with its key suppliers and customers, to adapt or respond in a speedy manner to marketplace changes as well as to potential and actual disruptions, contributing to agility of the extended supply chain.".

In their literature review, Do et al. (2021) indicated that supply chain agility has shifted from a customer demand-centric strategy focusing on competitive advantage into a risk and disruption management initiative. In addition, agility can allow firms to create adding values and increase competitive advantage (Tse et al., 2016).

### 2.2.2 Dimensions of supply chain agility

There are many elements of agility which relate as much to the supply chain networks as they do to the individual firms. (Chirstopher & Beck, 2004). According to Gligor et al. (2013), supply chain agility consists of five dimensions as illustrated in table 2. These dimensions are associated with the physical capabilities and cognitive capabilities of the company. Cognitive capabilities (alertness, accessibility, and decisiveness) are needed to timely identify and gather information for decision making, while physical capabilities (swiftness and flexibility) enable the actual operational adjustments and implementation (Gligor et al.,2013).

**Alertness** as a dimension of supply chain agility refers to the ability to be aware of supply and demand changes in a timely manner (Gligor et al.,2013). To stay alert, it is important to maintain market sensitivity, meaning being able to sense the trends and happenings in the market (Christopher,2000). Moreover, predictability of uncertainties can be enhanced with analytical capabilities, which is defined by Jindal et al. (2021) to be one of the most important criteria in determining supply chain agility. Having an end-to-end visibility to supply chain is another critical requirement for alertness, as it provides a clear

awareness to the current state of demand and supply, procurement, production and inventories (Christopher and Peck, 2004).

*Table 2: Dimensions and enablers of supply chain agility [adapted from: Gligor et al. (2013: 4-12)]*

| Capability type | Dimension | Definition |
|---|---|---|
| Cognitive | Alertness | "Ability to quickly detect changes, opportunities, or threats" |
| | Accessibility | "Ability to access relevant data" |
| | Decisiveness | "Ability to make decisions resolutely" |
| Physical | Swiftness | "Ability to implement decisions quickly" |
| | Flexibility | "Ability to modify the range of tactics and operations to the extent needed" |

**Accessibility** is crucial in agility, as it allows firms to reach the most necessary data needed for decision making. Agile supply chain must be information-based (Gligor et al.,2013), where stakeholders share real-time information and perform joint planning. Information integration allows supply chain partners to align processes, gain better visibility, adjust resources, and response better to changes (Braunscheidel & Suresh, 2009). Tse et al., (2016) also highlighted in their study that active knowledge seeking and engagement with suppliers and customers enables the accessibility to the most up-to-date market demand and partner competences.

**Decisiveness** comes as a major dimension of supply chain agility, as decision making triggers further activities to be done for responding to changes or disruption. Strategic commitment of top management is the most affecting factor in achieving agility, which is supported by a well-understood need for agility, alignment of agility into supply chain's vision and objectives, as well as technical and financial management support (Sangari et al.,2015). Utilizing supply chain technology such as MRP system could help managers make well-informed decisions in a timely manner (Ishak et al.2022). Decisiveness together with alertness and accessibility form cognitive capacities of firms to process information into actions (Gligor et al.,2013).

**Swiftness** or speed in the context of supply chain agility refers to how quickly decisions can be implemented (Gligor et al.,2013). Three main building blocks for improving speed in supply chain, proposed by Christopher and Peck (2004), are: streamlined processes (simplified processes with reduced number of steps and parallel activities), reduced in-bound lead-times (subject to supplier's competence and responsiveness), and

non-value-added time reduction (reducing the non-value adding time in the supply chain pipeline). Agarwal et al. (2007) also indicate that delivery speed, process integration, IT capabilities are among the variables contributing to the swiftness of supply chain.

**Flexibility** is the last building block for supply chain agility, which describes the operational ability to make efficient changes internally and across the supply chain network via effective stakeholder relationship management (Fayezi et al., 2017). According to Swafford et al. (2006), supply chain agility is affected by the following flexibility factors: sourcing flexibility, manufacturing flexibility and distribution flexibility. They define procurement flexibility as the ability to consider a variety of supply options in response to changing sourcing requirements. Manufacturing flexibility enables a firm to alter its capability and product variety in response to changes in component supply and demand, or to employ technological improvements of processes (Swafford et al., 2006). Distribution flexibility reflects a firm's utilize logistics infrastructure and adjust delivery capabilities to fulfill customer requirements (ibid).

### 2.2.3 Enablers of supply chain agility

Enablers of supply chain agility can be categorized into two types. *Proactive enablers* serve as preventive risk management approaches implemented prior to the disruptions; *Reactive enablers* are referred to as the approaches used to response to the disruptions once they have occurred (Braunscheidel & Suresh,2009; Christopher, 2000; Lee, 2004; Swafford et al., 2008; Tse et al., 2016). Figure 4 illustrates Humdan et al. (2020)'s integrated framework of supply chain enablers.

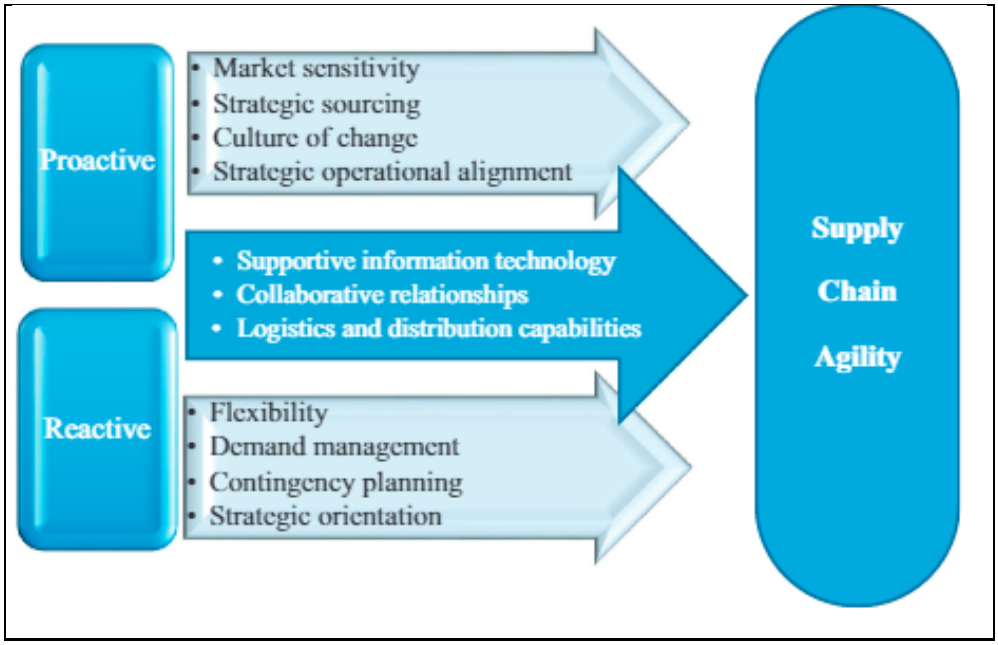


*Figure 4. Enablers of supply chain agility (Humdan et al., 2020)*

#### 2.2.3.1 Proactive enablers

The proactive enablers focus on increasing market trend awareness, ensuring efficient source of supply, embracing continuous improvement, and harmonizing operational capabilities (Humdan et al., 2020).

**Market sensitivity** acts as a key antecedent for supply chain agility, without which a firm's supply chain will face difficulties in seizing market opportunities and adjusting its operations in response to changes (Aslam et al.,2018). Having a well-developed market-sensing capabilities allows firms to better understand supply chain partner activities (Tse et al., 2016), capture market data and identify key patterns needed for supply and manufacturing resource planning (Aslam et al.,2018).

**Strategic sourcing** is proved by Chiang et al. (2012) to have a strong relation to supply chain agility. Their empirical study indicates that process integration, information sharing, supplier development, sourcing flexibility and multiple sourcing are elements of strategic sourcing that can improve supply chain agility.

Additionally, supply chain agility is anteceded by **operational alignment** through the integration of internal and external processes (Braunscheidel & Suresh, 2009), interest alignment between supply chain partners (Lee, 2004) and IT integration (Swafford et al., 2008). This is important especially when operational activities are handled by external partners such as logistics systems handled by third party service provider or production

outsourcing. Blome et al. (2013) further highlights that quality of procedures and workflows should be regularly assessed through process mapping to ensure streamlined and effective infrastructure for a more agile supply chain.

Achieving supply chain agility also requires **a culture of change**. A study done by Sangari et al. (2014) has indicated that maintaining a culture that fosters changes and active learning is the determinant of achieving agility in the supply chain. They believe that a culture of change allows firms to review and re-evaluate supply chain strategies that enhance agility. Management support plays a key role in creating and maintaining culture changes at an organizational level (Christopher & Peck, 2004).

#### *2.2.3.2 Reactive enablers*

Within the reactive approach, four main enablers of supply chain agility are flexibility, demand manipulation, backup planning and strategic orientation.

**Flexibility** is considered both a dimension (Gligor et al., 2013) and an enabler (Agarwal et al., 2007; Humdan et al., 2020) of supply chain agility. As covered in chapter 2.2.2, flexibility in supply chain is reflected in manufacturing, procurement and distribution perspectives. According to Sheffi and Rice (2005), flexibility in sourcing is associated with how supplier relationship can be aligned with procurement strategy, for instance whether to have close relationship with single supplier to maintain strong purchasing power, or to have with multiple suppliers to mitigate the risk of supply disruption. In terms of manufacturing, the authors specify that having multiple capabilities at different plant locations allows for continuing production activities when one plant is disrupted. Moreover, they indicate that for distribution, flexibility concerns firms' ability to customer demand adjustment and prioritization. Outside of the supply chain processes, flexibility in product design and engineering is also essential in ensuring agility (Braunscheidel and Suresh 2009).

**Demand management** as a reactive approach of agility used to manage demand-supply imbalance during disruptions. Tomlin and Wang (2011) specify two main approaches to manage demand: product switching and rationing. According to them, supply disruption can be mitigated by inducing customers to accept alternative products that are not supply-constrained. During the 1999 Taiwan earthquake that delayed the computer components to the US, while other big tech companies could not fulfill customer demand, Dell was able to utilize pricing and customer service strategies to shift customer demand from products that were in shortage towards other available options (Lee, 2004; Sheffi & Rice, 2005). When

switching product is not possible, firms might consider rationing – strategic allocation of supply among customers, or temporary increase of prices to reduce demand (Tomlin & Wang, 2011).

In case of disruptive incidents, having **contingency plans** and ability to implement backup plans is important for building supply chain agility (Lee, 2004). Common redundancy tactics used for increasing resistance against disruptions include the use of safety stock, backup supplier and additional production capability to ensure customer order fulfillment (Sheffi and Rice, 2005; Ivanov et al., 2017). A well-known example of successful contingency plan utilization is Nokia. In response to the sudden microchip shortage caused by a fire at its supplier Philips' plant, Nokia was able to continue manufacturing by having backup supply resources, while Ericson suffered from production set back and delays in new product launch (Lee,2004). Furthermore, backup plans provide a better protection when they can be implemented with high magnitude in a timely manner, which can be enabled by investing in additional internal capacities and access to third party capacities (Tomlin & Wang, 2011)

Braunscheidel and Suresh (2009) emphasize the impact of **organizational orientation** on supply chain agility. Particularly, they indicate that market orientation (customer, competitor and interoperation – oriented understanding and behaviors) provides firms with a better level of process integration and flexibility which fosters supply chain agility. In addition to market orientation, the authors also specify that firms that are oriented to learning can better achieve supply chain agility by actively assessing their current operations and looking for better ways of working.

#### *2.2.3.3 Multifunctional enablers*

Some enablers of supply chain agility are either proactive or reactive, meaning that they might be needed both before and after disruptions. According to Humdan et al. (2020)'s framework, they are logistics capability, collaborative relationship, and information technology.

**Logistics capability** is a factor needed for achieving agility, as it ensures the integration and alignment between operational activities and systems that help reduce redundancy while maintaining operational efficiency across the supply chain (Mentzer et al., 2004). As one of the aims of agility is to ensure responsiveness to customer demand (van Hoek et al., 2001; Lee, 2002; Ismail & Sharifi, 2006), ensuring logistics capabilities would

enhance responsiveness to market changes and supply uncertainties to ensure customer demands are met (Stank et al., 2005). Logistics capability concerns both demand-oriented and supply-oriented flows, as well as internal and external coordination and information sharing (Mentzer et al., 2004).

Various studies have emphasized that **collaborative relationship** between partners across the supply chain is a crucial factor of agile supply chain, which involves high level of information sharing and trust, as well as collaborative work and joint planning within different processes and functions (Lee, 2004; Lin et al., 2006; Agarwal et al., 2007; Braunscheidel & Suresh, 2009; Gligor et al.,2013). Collaboration helps reduce uncertainty by enhancing visibility across the upstream and downstream of the supply chain (Christopher & Peck, 2004). Strengthening partner relationships by aligning mutual interests also increases partner's reliability and competence (Lee 2004).

Last but not least, firms have been highly dependent on **information technology** (IT) to facilitate agility in supply chain (Wu & Angelis, 2016). It enables market data sensing (Christopher, 2000), fosters information acquiring and sharing between supply chain partners (Lin et al., 2006; Agarwal et al., 2007; Sheffi, 2015) and increases flexibility in supply chain processes (Swafford et al.,2008). Ivanov and Dolgui (2021) indicates that data-oriented digital capabilities are needed in both proactive planning activities as well as reactive real-time control in today's turbulent market environment. Various academic papers have addressed the common IT tools relevant for supply chain agility. Enterprise resource planning (ERP) were for example among the core supply chain systems needed for managing end-to-end goods and information flows between functions, which allows for efficient resource planning, scheduling and decision making (Baryannis et al., 2019). Moreover, sensor and robot-powered manufacturing systems, tracking and tracing (T&T), radio-frequency identification (RFID) as well as Internet of things (IoT) have been highly adopted in the past decades for real-time data accessibility, disruption alerts, fast response to changes as well as enhanced operational alignment and collaboration among all supply chain partners (Ben-Daya et al., 2019; Ivanov & Dolgui, 2020; Katsaliaki et al., 2021). Technologies of the new era are also bringing significant benefits to the supply chain and help reduce the ripple effect (Ivanov et al., 2019). For instance, big data analytics, machine learning and artificial intelligence help companies increase value creation through advanced prescriptive analytics, increase forecasting and planning capabilities as well as enhance visibility (Chen et al. 2012; Choi, 2018). Industry 4.0, IoT-powered cyber-physical integrated systems that allow for

automation and customization of supply chain processes, enable market flexibility and responsiveness to customer demand (Ivanov et al., 2019) Traceability and transparency of supply chain transactions will be significantly improved thanks to the evolution of blockchain technologies (Katsaliaki et al., 2021). Successful implementation of IT for agility in supply chain does not only depend on the IT infrastructure but also the organizational competence, culture as well as continuous engagement of trading partners (Wu & Angelis, 2016; Sharma et al, 2017).

### 2.2.4 Impacts of supply chain agility

According to Eckstein et al. (2015), supply chain agility positively affects organizations both operationally and financially.

Having an agile supply chain contributes to firm's financial performance in many ways. It allows for a better synchronization of supply and demand (Christopher, 2000) and efficient supply chain disruption management (Swafford et al., 2006; Blome et al., 2013). Elements of agility such as alertness to information and supply chain flexibility helps implement contingency plans in a cost-efficient way to cope with market velocity and uncertainties (Lee 2004). Improved customer demand fulfillment and on time deliveries through agile product and information flows enables firms to ensure customer satisfaction and thus increase profitability (Braunscheidel & Suresh, 2009; Gligor et al.,2013).

Supply chain agility also has various benefits on operational performance, which is reflected through "customer satisfaction, quality improvement, cost minimization, delivery speed, new product introduction, service level improvement, and lead-time reduction." (Agarwal et al., 2007:453). Flexible and timely adjustment of manufacturing processes, relocation of inventories and production facility, ability to switch supplier contribute to shortened lead times, enhanced delivery accuracy and service quality (Swafford et al., 2006; Eckstein et al.,2015). As supply chain agility is powered by collaboration, data sharing and market sensitiveness, it not only helps minimize uncertainties but also identify new market opportunities to enhance competitive advantage (Perera et al.,2019). Under high product complexity, supply chain agility improves responsiveness to changing customer demand by providing flexibility in product design and engineering (Braunscheidel & Suresh 2009). Agility in supply chain also allows for prompt recovery from disruptions while ensuring normal business continuity and reducing long-term negative impacts (Lee,2004). Empirical studies have also the positive impacts of supply chain agility on firm performance in

different industries such as telecommunications (Collin and Lorenzin, 2006), oil and gas (Yusuf et al., 2014), electronics (Tse et al.,2018), fashion (Chan et al., 2017), and manufacturing (Blome et al., 2013; Swafford et al., 2008)

## 2.3 Semiconductor shortage

Various devices, equipment, network processors, technological applications and innovation heavily depend on the production and supply of semiconductors (Yong, 2021). Thus, shortage in semiconductor supply can cause significant negative impacts across industries. The following sections provide an overview of the semiconductor supply chain, followed by implications of semiconductor shortage on the global supply chain.

### 2.3.1 Semiconductor supply chain

Semiconductor is a material that conducts electricity whose physical properties lie between an insulator (such as glass) and a pure conductor (such as Aluminum) (Singh & Agnihotri, 2009). Khan et al. (2021) describes the semiconductor supply chain to include three main phases: research and development, production, and distribution. As illustrated in figure 5, the chip production is broken down into design, fabrication, and ends with assembly, testing and packaging, which could require an overall lead time of 10-15 weeks (Chien et al.,2018).

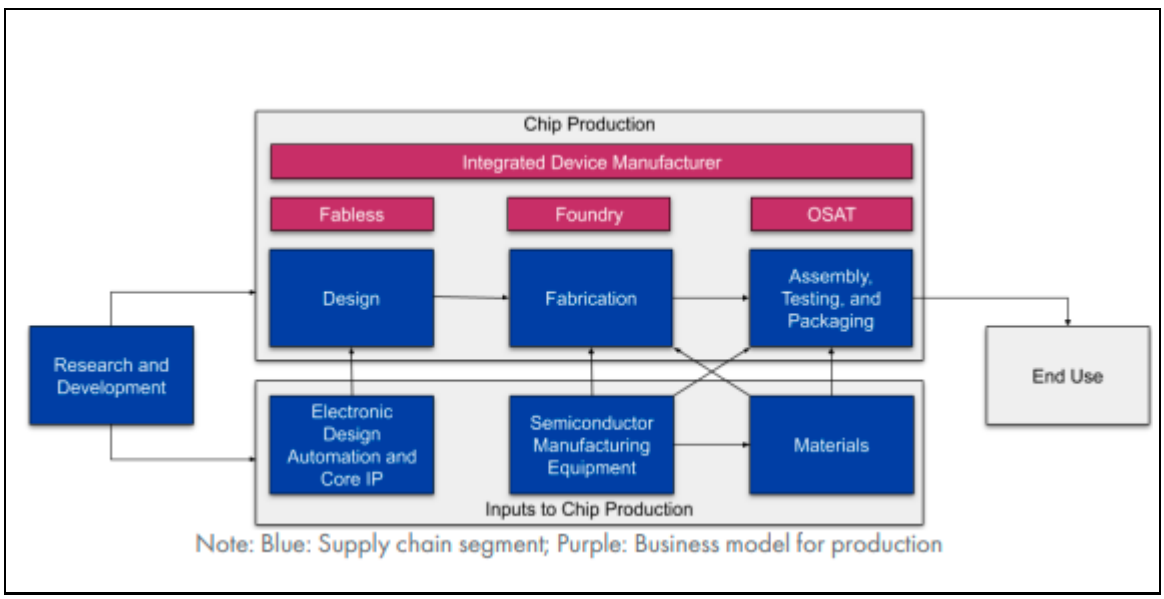


*Figure 5. Semiconductor supply chain (Khan et al., 2021)*

Supply chain of semiconductors is usually indicated as complex due to “long fabrication cycle times, high levels of stochasticity, and non-linearity in the manufacturing process” (Sun & Rose, 2015:1). In addition, each production phase can be done in-house or outsourced, and is typically performed in several different locations around the world, which is causing difficulties in supply chain management (Chien et al.,2018).

In addition to the production complexity that can involve more than 500 processing steps, the semiconductor supply chain is also bearing the pressure from volatile market with rapid technological changes resulting in unpredictable demand (Sun & Rose, 2015; chien et al.2018). For instance, fabrication process is usually done out in industrialized areas such as the US, Japan and Taiwan while the chip assembling, testing and packing are carried out in developing countries such as Vietnam and Malaysia (Leslie,2021). Due to such complex manufacturing process involving high capital expenditure and infrastructure costs, it is difficult for semiconductor makers to expand production capacity as it is expensive and time-consuming (Chien et al.,2018).

### 2.3.2 The semiconductor supply shortage and its implications

While the automotive industry’s demand for semiconductors decreased in response to the the global lockdown during the COVID-19 pandemic, the shift to remote working and studying significantly increased the need for consumer electronic equipment such as PCs and workstations (Attinasi et al., 2021). As the pandemic situation recovered, many firms including automakers were simultaneously expanding production, causing a sudden demand surge that could not be fulfilled by the production of semiconductors (Yong, 2021).

Increasing demand from end customers forced automakers and consumer electronics manufacturers to place larger orders to chip designers, that eventually overwhelmed foundries/chip manufacturer with an extra wave of demands that cannot be efficiently fulfilled (Marinova & Bitri, 2021). This shift of demand creates pressure towards the upstream of the supply chain, as shown in figure 6.

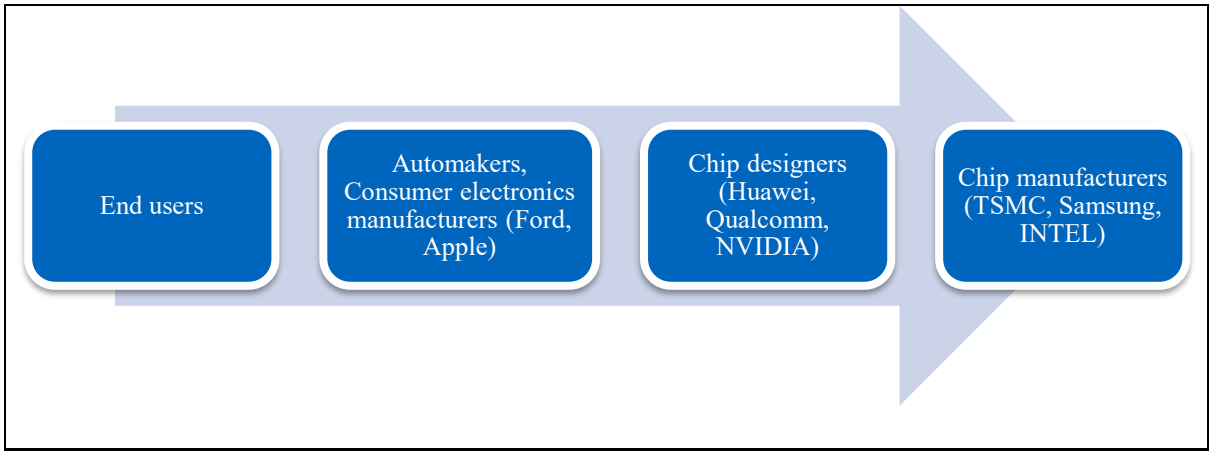


*Figure 6. Increase of demand for semiconductor [adapted from: Marinova & Bitri (2021) ]*

In addition, the outbreaks of COVID-19 in Southeast Asia resulting in factory lockdowns and occurrence of server weather conditions affecting manufacturing plants in Japan and US further provoked the global supply shortage of semiconductors (Leslie, 2021). Insufficient supply of semiconductors generates production incapability and delays towards downstream supply chain. Large tech providers such as Apple and AMD, for instance, ended up postponing their new product rollout due to lack of component supply (Yong, 2021).

Supply disruptions resulted from by the semiconductor shortage have several negative impacts on firm's operational and financial performance including reduced production capacity, long manufacturing lead time, high raw material prices, decreased gross margin and increased holding inventory (Ishak et al.,2022). Moreover, supply and demand imbalance might force companies to delay customer orders, prioritize between customer demands or increase prices, which could affect company's credibility and customer satisfaction (Tomlin & Wang, 2011). The bigger challenge for companies during the semiconductor shortage is in demand forecasting and predicting whether capacity will be able to meet demand when supply capability in uncertain (Yong, 2021).

The semiconductor crisis exposes the challenges in the chip production ecosystem and chip supply chain, as well as the global supply chain's high vulnerability to disruptions (Marinova & Bitri, 2021). In facing such disruptive event, it is crucial for organizations to maintain an agile supply chain that can anticipate risks, implement contingency plans, response in a timely manner, and recover back to normal operation while ensure customer demand fulfillment and operational efficiency (Ishak et al.,2022).

## 2.4 Conceptual framework: Agility in supply disruption management

As covered in previous chapters, previous literature has proved the key roles of agility in coping with unpredicted changes, uncertainties, and disruptions in the supply chain. Only Calvo et al. (2020) has identified the scope of agility within the disruption management process. Their framework specifies that agility is applicable only in the later phase of the disruption cycle - after the disruption has occurred. According to Braunscheidel and Suresh, (2009), however, agility brings value for both pre-disruption risk mitigation as well as post-disruption responsiveness and recovery. Moreover, Calvo et al. (2020) do not specifically include different elements of agility into their framework Thus, to acknowledge these research gaps and synthesize the previous literature review, a conceptual framework "Supply chain agility in supply disruption management" (figure 7) was created for this study by combining the concepts studied from the literature review: disruption management cycle, the key dimensions of agility, and the enablers of agility in supply chain.

The illustration of the framework can be interpreted as following. Supply disruption management follows the four-step cycle. 'Mitigation' and 'Detection & Preparation' stages are included in the pre-disruption phase where proactive approaches are taken to mitigate risks, detect and prepare for the disruption. This phase incorporates 'Alertness' and 'Accessibility' dimensions of supply chain agility, which are enabled by Humdan et al. (2020)'s defined factors 'Market sensitivity', 'Strategic sourcing', 'Culture of change' and 'Operational alignment'. Once the disruption has occurred, reactive actions drive the 'Response' and 'Recovery & learning' stages. 'Flexibility' and 'Speed' are the elements of agility presenting in these stages, which are anteceded by Humdan et al. (2020)'s proposed enablers 'Operational flexibility', 'Demand management', 'Contingency planning' and 'Strategic orientation'. Across the whole disruption management cycle, 'Decisiveness' factor of agility is required to facilitate needed actions before, during and after the disruption. The level of decisiveness is driven by 'Supportive top management', 'Strategic collaboration' as well as 'IT capabilities'.

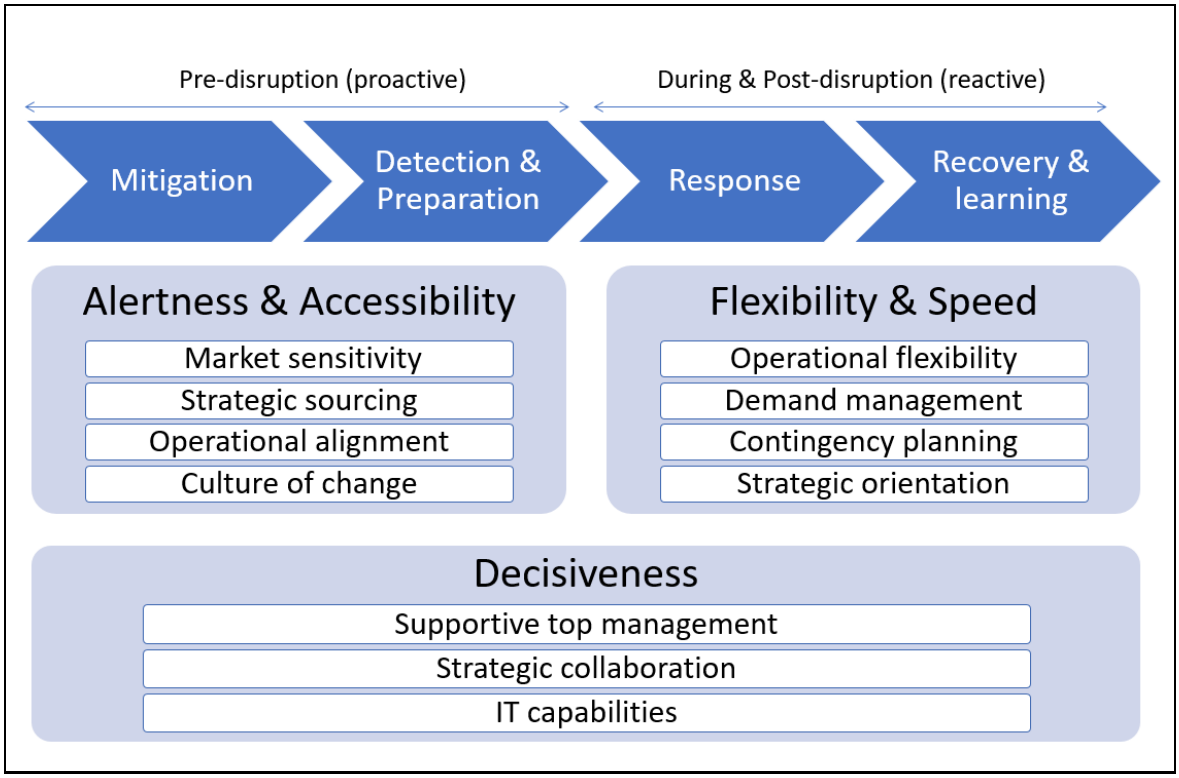


*Figure 7. Conceptual framework : Supply chain agility in supply disruption management*

The following subsections will further discuss the framework elements and elaborate them in the context of the semiconductor shortage.

### 2.4.1 Pre-disruption: alertness and accessibility

Effective disruption management starts with foreseeing the potential risks of disruption, coordinating mitigation plans and preparing for the disruption event. In the pre-disruption phase, alertness and accessibility dimensions of agility should be focused to mitigate risks as well as gather information about the possible disruptions and their impacts. This is enabled by market sensitivity, strategic sourcing as well as to maintain operational alignment and a culture of change.

One of the most crucial drivers of supply chain agility the sensitivity to market changes, which affects the level of responsiveness to changing demand and lead time reduction (Agarwal et al., 2007). In the case of semiconductor shortage, accessing and analyzing the market trends is important to sense the fluctuation in demand and supply fluctuations. Delayed components and increasing supplier lead time are also the signs of disruption that should be detected and assessed early enough. In addition, a study from

Perera et al (2019) adds that inter-organizational relationships with suppliers and customers help firms stay ahead of their rivals by having access to the latest market information.

As a firm's supply chain agility also highly depends on its partners (Braunscheidel & Suresh, 2009), strategic sourcing holds a key role in managing supply disruptions and ensuring agility. Strategic sourcing is defined as a "supply management process used to locate, develop, qualify and employ suppliers that add maximum value to the buyer's products and services" (Sollish & Semanik, 2011: 1). Having multiple sources of supply for the same products is considered as a common approach to mitigate supply disruption risk (Ivanov et al., 2017). However, in the context of the global chip shortage, having multiple suppliers might not be a feasible solution because many suppliers are affected by the shortage at the same time. In addition, dividing demand among multiple suppliers might reduce a firm's buying power and make them a secondary priority of suppliers (Blome and Henke, 2009). Earlier literatures suggest that maintaining strategic supplier relationships is helpful in increasing commitment, enhance information sharing and collaboration which is crucial in gaining visibility to market changes (Chopra & Sodhi, 2004; Lee, 2004; Sheffi, 2005)

Alignment of supply chain operations plays an important role in achieving supply chain agility and preparing for disruptions. According to Gligor and Holcomb (2012), operational alignment is concerned with the alignment of interests and actions, which help companies integrate processes and develop collaborations with different partners within the supply chain. In the event of component shortages, alignment between internal supply chain functions (manufacturing, sourcing, and customer deliveries) as well as external partners (suppliers, customers, subcontractors, 3rd party providers) is crucial in gaining external learning and information (Tse et al., 2016). Information systems support companies in increasing agility by building alignment and integration between supply chain operations (Zhou et al., 2018).

Adoption of agility requires an adoption of new knowledge not only in organizational operations but also in mindset and culture. The ability of an enterprise to absorb external information and adapt it into company culture can increase supply chain agility (Russell, & Swanson, 2019). Maintaining a culture of change provides a basis for enhancing the necessary competencies and capabilities for agility (Sangari et al., 2015). Moreover, it is important for firms to keep up with the latest knowledge of the supply chain through active

learning, which fosters speed and flexibility when responding to market disruptions (Tse et al., 2016).

### 2.4.2 Post-disruption: flexibility and speed

Once a disruption is detected, companies should act quickly to mitigate the impacts of ripple effects and return back to normal supply chain operations in a timely manner (Chen et al. 2019). Flexibility and speed are the main factors to anticipate responses and recovery that reduce negative impacts and ensure supply chain operation continuity. This is associated with the enablers of agility including operational flexibility, demand management, backup planning and strategic orientation.

Flexibility in supply chain is referred to as the ability to adjust processes and capabilities allowing companies to quickly detect and response to (Sheffi & Rice, 2005). Flexibility in supply chain should be associated with goods flows starting from sourcing, to manufacturing and to distribution (Sheffi & Rice, 2005; Swafford et al., 2006), as covered in chapters 2.2.2 and 2.2.3.2. Flexibility is essential in managing complex operations between various suppliers and customers tiers within the supply chain (Pettit et al. 2010). In the event of semiconductor shortage causing component supply disruptions globally, companies need operational flexibility to response efficiently to uncertainties and changes while reducing negative impacts. Young (2021) specifically indicates that having a flexible production system utilizing a wide range of components is crucial to cope with the current semiconductor shortage as well as similar future crisis. Moreover, flexibility is important in the implementation of contingency plans.

Adoption and implementation of contingency plans is crucial in response to supply disruption. Different kinds of mitigation approaches have been suggested to reduce the negative impacts of supply disruptions: safety stock to be used in case of emergency, multi-sourcing or backup supplier to find alternative supply of materials, and backup production site to keep manufacturing activities going (Sheffi and Rice, 2005). Contingency plans in product design are also useful in case of material disruption (Ivanov, 2020).They also indicate that contingency approaches can contribute to increasing costs while offering less leverage compared to flexibility capabilities. In the context of semiconductor shortage, having extra inventories of critical components in buffer stock can help to ensure production and customer delivery, however, when safety stock is used up, finding alternative sources of supply shall be considered (Ishak et al., 2022).

In the aftermath of supply disruption, companies should make decisions related to demand management, in particular, which products to sell and which customers to serve first. According to Sheffi and Rice (2005), it is crucial to have a reasonable process to determine priorities for supply allocation during the post disruption period. Some prioritization criteria suggested by the authors are for instance profitability, long-term relationship criticality, and costs associated with serving the customer. Postponement in demand fulfillment can be utilized to allow for implementation of contingency plan in product reconfiguration (Ishak et al., 2022).

Strategic orientation is another factor enabling responsiveness during the disruption. According to Braunscheidel and Suresh, (2009), maintaining a market-oriented and learning-oriented culture allows companies to enhance supply chain integration. They elaborate that market orientation includes customer, supplier and interoperation-oriented knowledge; while learning orientation focuses on learning commitment, open-mindedness and common vision. During semiconductor shortage, having understood different customers' attributes, values and needs can enable effective demand prioritization. Moreover, the knowledge gained from external learning can be transformed into a firm's capability which improves performance (Tse et al., 2016). A study by Chen et al. (2019) also remark the implication of learning during the post disruption phase. In particular, they mention that the review of disruption causes, documentation of disruption profile and examination of contingency plans after the disruption has ended allow companies to re-design supply chain and reform disruption management strategies to become more responsive.

### 2.4.3 Throughout the disruption management cycle: Decisiveness

Appropriate and timely decision making is required both before and after the disruption. Chen et al. (2019) emphasize that initial decisions should be made during the pre-disruption phase so that pro-active actions can be facilitated, which can significantly affect the disruption's outcome. In the event of semiconductor shortage, such decisions can be related to contingency planning activities such as setting partnership with multiple/backup suppliers or ordering goods to safety stock. During the disruption, ability of firms to make resolute decisions is crucial to ensure responsiveness to changes (Gligor,2013).

Top management's support and commitment is crucial to achieve agility in coping with supply disruptions as it allows for informed decision making, increased flexibility and

collaborative relationship among supply chain partners (Barve, 2011). In addition, Chen et al. (2019) specify that decision maker's experience, leadership skills and behavioral attributes have an impact on the disruption recovery. In addition, access to sufficient data about the disruptions and its impacts on the company's performance should be clearly identified (Jindal et al.,2021) with the help of strategic collaboration and information technology in order to foster effective decision making. Agarwal et al. (2007) emphasize that the management of the supply chain should adopt strategies that promote strong network of partners through trust, collaboration, process integration and better use of IT tools.

As supply and demand information required for sufficient decision-making are from suppliers and customers (Jajja et al., 2018), maintaining collaborative relationships with these supply chain partners is crucial in achieving agility performance. Close partner relationship fosters trust, information sharing and joint planning, which enables supply chain integration (Jajja et al., 2018) and enhances flexibility and responsiveness (Barve, 2011). Supplier collaboration driven by long-term and mutually beneficial relationship increases suppliers' willingness to share risks and monitor their resources during unusual or disruptive circumstances, as well as allows the buying firm to understand, align and develop the suppliers' capabilities (Jajja et al, 2018). As delays in component supply happen globally during the semiconductor crisis, supplier collaboration-enabled decision making is essential in increasing buffer stock, identifying alternative resources, making emergency purchases and developing process flexibility. While managing supply activities is crucial during the chip shortage, customer collaboration should also be focused to manage demand fulfillment, reduce negative impacts and avoid damaging long-term relationships. Active information exchange with customer is needed to reduce the uncertainty in the forecast (Jajja et al, 2018) while ensuring that they are aware of the current supply situation (Sheffi & Rice, 2005), which in turn ease the decision-making process about demand allocation and prioritization during component shortage. Furthermore, Sheffi and Rice (2005) suggest that relationship with customers can be strengthened by helping them find new sources of supply and validate alternative suppliers, when the firm itself cannot fulfill their demand during component disruption.

IT capabilities in supply chain are crucial for enabling a fast collection and sharing of information across functions and partners (Alzoubi & Yanamandra, 2020). Market sensitivity and information sharing supported by IT capabilities are needed to cope with unpredictable disruptions in a timely manner while maintaining competitive advantage in

changing environment (Ngai et al., 2011). IT tools bring benefits throughout the whole disruption management cycle, as they increase visibility while preventing delayed decision making caused by disrupted information (Chen et al., 2019). When coping with the semiconductor shortage, firms can utilize information analysis tools to detect disruption risks during the pre-disruption phase (Pettit et al., 2010) while enhance responsiveness and recovery during the disruption through visibility, trust and cooperation among supply chain partners (Kamalahmadi & Parast, 2017). Katsaliaki et al. (2021) further emphasize the importance of investment in IT capabilities, which should be the main focus of the top management in collaboration with other supply chain tiers. However, there are other factors associated with IT tool adoption concerning managers including IT security and vulnerability of information assets that require risk monitoring of risk and contingency planning. (Chen et al., 2019).

This conceptual framework synthesizes the key theoretical points derived from the reviewed literature and will serve as a basis for the empirical data analysis of this study. The next steps of the research process involve data collection and data analysis. Hence, this framework will be used to design the interview protocol for collecting empirical data though semi-structured interviews with case companies. In addition, thematic data grouping can be developed based on the framework to support the data analysis and discussions of findings.

# 3 RESEARCH METHODOLOGY

This chapter presents the research methodology used in this thesis. Firstly, the choice of research methods is clarified, followed by a description of the research process. Next, a detailed discussion of the empirical data collection and analysis is provided. Lastly, the research's trustworthiness and limitations are discussed.

## 3.1 Research approach and process

The selected research method for this thesis is qualitative multi-case study. Qualitative research seeks to explore a social phenomenon by understanding and interpreting commonsense constructs and their usage in real-life settings (Gephart, 2018). Comparing to quantitative research method, which focuses on structured gathering of evidence in a controlled way (Walle, 2015), qualitative research offers more flexibility to study 'a wide range of variables, relationships, meanings, and processes' that allows for examination and reconceptualize of existing phenomena (Gephart, 2018:26). Case study is among the strategies of qualitative research which aims to "present complex and hard-to-grasp business issues in an accessible, vivid, personal, and down-to-earth format" (Eriksson and Kovalainen, 2008: 116). Case study explores the phenomenon from the viewpoint of the involved participants which, according to Eriksson and Kovalainen (2008), can elaborate theories and can be conducted on a single or multiple basis.

This study focuses on understanding how supply chain agility and supply disruption management is applied in the context of the global semiconductor shortage. As agility and disruption management in supply chain are highly associated with practical organizational operations and culture, qualitative research is a suitable approach to enrich the understanding of different processes in a flexible and contextualized way (Gephart, 2018). Moreover, as the semiconductor shortage is a relatively new event at the time this study is carried out, using qualitative approach would allow for exploration of unexpected events and holistic interpretation of realities (Rynes & Gephart, 2004). Due to the global scope and implications of the semiconductor crisis, multi-case study is selected to achieve a multidimensional and objective understanding of the topic.

Figure 8 describes the research process of this thesis. It starts with defining the research questions which serve as a basis for research method and theoretical concept selection (Eriksson & Kovalainen, 2008).

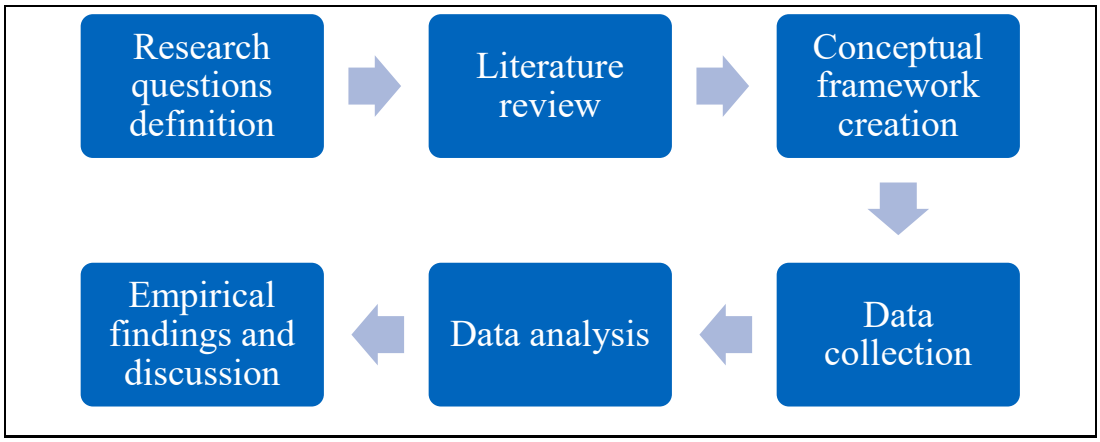


*Figure 8. Research process*

The main research question is: *How to utilize supply chain agility in supply disruption management during semiconductor shortage?*

The research question includes two sub-questions that aims at understanding the impacts of semiconductor shortage on companies' performance, examining the approaches to management supply disruption and exploring the role of supply chain agility in managing supply disruption.

*(1) What are the impacts of the semiconductor shortage on companies' performance?*

*(2) What is the role of supply chain agility in managing supply disruption?*

Once research questions have been identified, the literature review was conducted based on three main theoretical themes: supply disruption, supply chain agility and semiconductor shortage. Next, a conceptual framework was developed based on the theoretical literature review on earlier research. The conceptual framework reflects the study's focus and is used to interpret larger theoretical and practical perspectives of the phenomenon (Yin, 2011). The framework combines theoretical concepts of disruption management and supply chain agility, based on which the design of empirical data collection is constructed. According to Eriksson & Kovalainen (2008), the collection of any empirical data needs to be aligned with the theoretical background and research method of the study. They also emphasize that despite aiming at exploring phenomenon in a practical perspective, qualitative research is subject to some degree of theoretical concepts and is aimed to develop those further along the research process. Gathered data is then coded into different themes

used as a basis for analysis. Lastly, empirical findings are presented and discussed against the research questions and theoretical framework.

Empirical data of this research was collected through interview. This approach is suitable for the study because it can convey participant's subjective viewpoints about the phenomena and reflect their rationales for processes and ways of working (Gephart, 2018). Interview as a qualitative data collection method typically involves a series of questions and answers conducted between the researcher (interviewer) and the case study's representative (interviewee), as per Eriksson & Kovalainen (2008). Qualitative interviews are often open-ended which enables freedom and uniqueness in answers (Walle, 2015). Moreover, the thesis' author has an educational background and more than 4 years of working experience in supply chain management, as well as practical observation on the impacts of the semiconductor shortage, which justifies Walle (2015)'s indication that the interviewer should have some degree of specialized knowledge about the topic when conducting interviews. There are three types of qualitative interview: structured interview to which answers are standardized and controlled, unstructured interview which provides high level of freedom, and semi-structured which enablers certain variety in a guided direction (Walle, 2015; Eriksson & Kovalainen, 2008). Semi-structure interview is selected for this study, which includes an outline of topics designed based on the conceptual framework, but simultaneously allows for an adoption of new themes (Eriksson & Kovalainen, 2008). As this thesis is a multi-case study, semi-structure interview was conducted with several case companies.

## 3.2 Data collection

This section discusses the sample selection, interview protocol construction and interview process associated with the collection of empirical data.

### 3.2.1 Sample selection

The purpose of the empirical study is to explore how companies have managed disruptions caused by the semiconductor shortage and compare those practices to the theoretical concepts of supply chain agility in disruption management. The selection of case companies and interview participants is an essential part of qualitative case-study research. The sample selection of this study was done by applying principles of purposive sampling. In this

method, interview samples are selected based on pre-defined criteria to enable understanding and exploration of the research themes while ensuring some level of diversity needed for comparative analysis (Ritchie et al., 2013). According to Ritchie et al. (2013:80), selection criteria of purposive sampling is influenced by "a range of factors including the principal aims of the study, existing knowledge or theories about the field of study, hypotheses that the research may want to explore or gaps in knowledge about the study population.". In this study, the selection criteria are made mainly based on the research's main objective which is to explore how supply chain agility can be utilized to manage supply disruptions during the semiconductor shortage.

The selection of case companies was based on the type of business and product offerings. As the focus of the study is on semiconductor shortage, the companies selected for this study should have supply chain activities that are involved with electronic products and components. The interviewees were selected based on their job position, which should be closely related to the supply chain operations, and their awareness about the semiconductor shortage. In qualitative research, sample size is typically small because there is no need for prevalence and the data collected are rich in detail that requires in-depth analysis (Ritchie et al., 2013).

In total, semi-structured interviews were conducted with a set of 5 case companies. To enable a variety of perspectives, the selected organizations vary in industry and size, as shown in table 3.

*Table 3: Company data: overview*

| Number | Industry | Size | Interviewee's position | Interview date |
|---|---|---|---|---|
| 1 | Telecommunications | 300-500 | Delivery manager<br>Component engineer | 30.03.2022<br>26.04.2022 |
| 2 | Industrial machinery manufacturing | 100-300 | Managing Director | 31.03.2022 |
| 3 | Electronics manufacturing | 50-200 | Interim Manager in operations and supply chain | 01.04.2022 |
| 4 | Security | 200-500 | Buyer & Sourcing manager | 19.04.2022 |
| 5 | Machinery manufacturing | 50-100 | Technical buyer | 29.04.2022 |

All interviews lasted for one hour. The diversity of samples is also reflected in the different roles of interviewees including customer delivery manager, supply chain manager, component engineer, managing director, interim manager, buyers and sourcing manager. Interviewees were approached first to identify their interest in the topic and later to provide them with detailed information about the study, interview settings as well as a list of interview questions for preparation.

### 3.2.2 Interview protocol

The interview protocol was constructed based on the conceptual framework introduced in chapter 2.4. The interview questions were created and ordered following the two main parts: business background information and the supply disruption management practices during the semiconductor shortage. The interview questions are presented in Appendix A.

The first part of the interview protocol involves questions about the company's background, supply chain characteristics and products with the aim of understanding how these factors are associated with the semiconductor shortage. In addition, in order to answer research sub-question 1, an interview question about the impacts of the semiconductor shortage on the company's performance was included. The second part includes questions related to the key terms defined in the conceptual framework. The structure of this part was designed to follow the disruption management cycle with an aim to reflect the elements and enablers of supply chain agility.

All of the interview questions were designed to combine both structure and flexibility, which encourages open-ended meaningful answers instead of yes/no responses, as recommended by Ritchie et al. (2013). Furthermore, the broadness of interview questions was intended by primarily including "how" and "what" questions while avoiding leading questions that can direct interviewees to give answers that the researcher expects (Eriksson & Kovalainen, 2008; Ritchie et al., 2013)

### 3.2.3 Conducting interviews

Due to the COVID-19 situation and as the distance work recommendation was still in force in many companies, interviews were conducted remotely via Zoom application. Each interview session lasted for around one hour as an optimal length suggested by Ritchie et al. (2013) to achieve answers to the interview question as well as deep discussions around the topic. Moreover, since most of the case company participants are working at the

management level, it was convenient to find a one-hour time slot that fit into their schedules. In most of the cases, there was one company representative from the company who participated in the interview. With the first case company, the researcher was able to interview two representatives while with the fourth case company, there were two people participating in the same interview.

Prior to the interview day, interviewees were provided with detailed information about the research topic, objectives as well as the interview settings and a list of planned interview questions for preparation. Particularly, company representatives were informed in advance by email that the interview session will be audio-recorded, and their permission was confirmed once again on the interview day. Verbal recording is highly recommended in qualitative interviewing since it fully captures the original answers in interviewee's own language (Ritchie et al., 2013). Moreover, recording can free up the researcher's time for notetaking and allow for more active participation and interaction during the meeting. The discussions were recorded using both Zoom's recording functionality and mobile phone recorder as a backup. To foster interactivity during the interviews, the researcher and interviewees had their camera turned on for the whole time.

Each interview session was started by an introduction to the research topic and the researcher's background, as well as reconfirmation for audio-recording and organization's anonymity in the thesis. The interview continued with the introduction to the case company's background and the interviewee's role in the organization. Interview questions were asked according to the prepared interview protocol. As interview questions were designed to be open-ended that allowed for flexibility, some of the interviewee's responses already covered the next questions. Through active listening, the researcher was able to identify such cases and avoided asking for the same inputs. Thus, in such cases, the question was skipped completely, or was asked in a different way to gain more details. The interview ended with some generic concluding questions for the interviewee's overall thoughts about the topic.

## 3.3 Data analysis

The analysis of empirical data for this study was done by applying principles of Thematic Analysis which "seek to identify, make sense of and highlight the key themes in a rich qualitative data set so that important features of the research phenomena can be communicated to and understood by a wider audience" (King and Brooks, 2018: 220). In addition, the analysis was made in accordance with Yin (2011)'s five-step process of

qualitative data analysis illustrated in figure 9, including: (1) Data compiling, (2) Data disassembling, (3) Data reassembling, (4) Data interpreting, and (5) Concluding. The two-direction arrows imply that the steps can be revisited. These analytic phases can be utilized to make comparisons, identify patterns and develop explanations from the collected data while reducing the vulnerability of selectivity and bias (Yin, 2011).

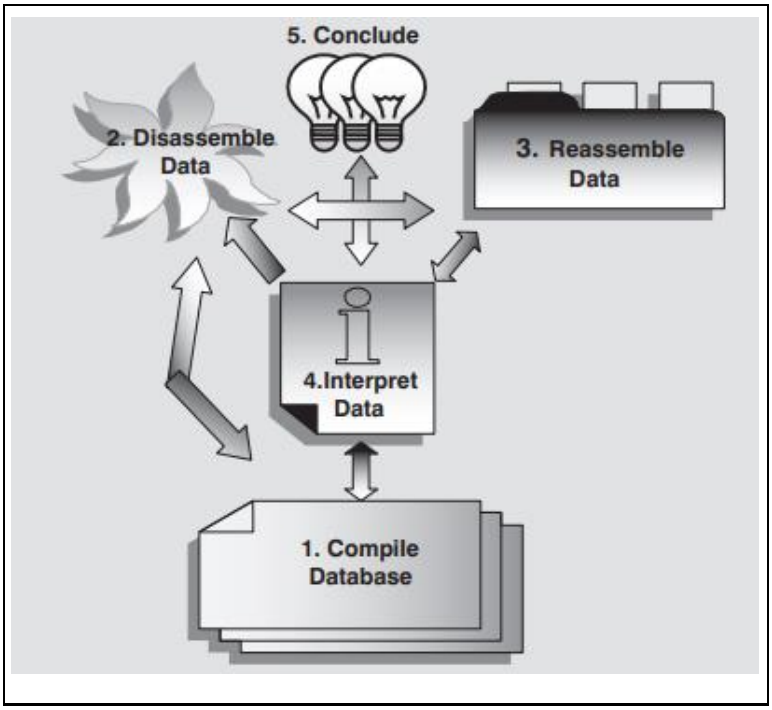


*Figure 9. Five Phases of Analysis and Their Interactions (Yin,2011)*

The first step of the qualitative data analysis process is to arrange notes and compile data into a set of records or a 'database' for easy access and systematic organizing of data before the actual analytics starts (Yin, 2011). The audio recordings from the interviews of this study were transcribed in an Excel file. The data were organized using matrix principle in the Excel file so that each column denotes a company case while each row classifies the data by themes or codes that would be defined in the second step.

In the second step of the process, the compiled data is broken down into smaller pieces or segments and can (optionally) be assigned with new labels or "codes" (Yin, 2011). The term 'coding' is used in thematic analysis to describe a process of indexing data with abbreviations to identify relevant themes needed to answer the research questions (King & Brooks, 2018). The data compiling phase in this study was done using Template analysis which, according to King and Brooks (2018), is a style of thematic analysis used to develop a flexible coding template from a subset of data, which can be further revised and redefined

to better capture rich meanings from data. Moreover, the authors indicate that template analysis can include the use of both inductive coding (in which themes are identified inductively from the collected data) and deductive coding (in which themes are derived from previously determined theoretical or practical concerns). The use of pre-defined themes (also known as priori themes) in data analysis is useful to ensure relevance of the analysis and improve the theories (Eriksson & Kovalainen, 2008). The themes of this research were originally derived from the established conceptual framework (chapter 2.4) which were also used in developing the interview questions. However, as suggested by Eriksson and Kovalainen (2008), codes developed from the empirical data is preferable to enhance objectivity. King and Brooks (2018) also specify that priori themes should be used in a limited manner, and redefined or removed if needed. Thus, the pre-defined themes were re-evaluated against the collected empirical data and additional codes were also identified to ensure multidimensional views of the topic.

Once common themes and codes have been identified, the next step is to rearrange and recombine the data using visuals or arrays to discover different patterns (Yin, 2011). In this thesis, individual quotations from the interviews were listed under each of the thematic groups in an Excel file to identify similarities and differences between the disruption management practices of each company. Two-dimensional matrices with columns and rows are recommended by Yin (2011), thus Excel is considered a suitable tool for performing this step.

The final stages of the analysis process involve data interpretation and conclusion. The resembled data should be evaluated to determine the main relevant analytical points, through which the need for revisiting the previous steps for achieving more complete and accurate findings might arise (Yin, 2011). In this study, the empirical findings were compared to the previous theories to assess their application in practices. The result of this step will be presented and structured under the key themes forming the sub-chapters of chapter 4 in this thesis. Finally, conclusions are drawn from the entire study that synthesize theories, empirical findings and answers to the research questions.

## 3.4 Research trustworthiness

Guba and Lincoln (1982) address the importance of evaluating a qualitative study's trustworthiness. This research follows the authors' recommended four criteria to assess trustworthiness which are credibility, transferability, dependability, and confirmability.

The first criterion is credibility, which describes the assurance that data have been properly collected and interpreted, so that the phenomenon that was studied is correctly reflected through findings and conclusions (Yin, 2011). Maxwell (2013) suggests that it is essential to produce a complete understanding of the research phenomenon and cover it with detailed and varied data. In this study, the research topic was studied through intensive literature review from which a conceptual framework is designed and used to collect empirical data. Moreover, the researcher has work experience in supply chain management whose observation and understanding of the topic is beneficial. In addition, to enhance credibility, this study applies the triangulation approach which can be referred to as "the use of different methods and sources to check the integrity of, or extend, inferences drawn from the data" (Ritchie et al., 2013:46). The empirical data analysis of this study followed the 5-step approach suggested by Yin (2011) that ensures proper pre-processing, thematic analyzing and interpreting of data. During the analysis process, earlier steps were revisited to enhance data coding. The collected data were compared with the theoretical concepts as well as across the different case companies to identify similarities and differences.

Secondly, transferability is referred to as ability to generalize and apply results of a research across different settings, which can be enabled by providing readers with sufficient information about the research that can be applicable to a new context (Lincoln & Guba, 1985). The transferability of this thesis was fulfilled firstly through a detailed description of research objectives, research scope and the application of different qualitative methodologies. Moreover, external validity can be ensured by explicitly comparing the study results across different settings (Maxwell, 2013). The multi-case study approach was selected to study the thesis topic, which enabled a diversity of perspectives from case companies across different industries on how they have dealt with the semiconductor shortage. The result of this thesis will reflect the phenomenon from different angles and act as a suggestion for other companies to apply in similar situations.

Third, dependability can be referred to as the consistency of findings which, if repeated, can obtain similar results. This study's dependability is ensured though sample selection process in which the case companies were selected based on pre-defined criteria to ensure consistency. The case companies' relevance and interest in the topic were assessed and confirmed in advance before proceeding further to interviewing stage. In addition, interview participants were provided in advance with detailed information about the research topic and interview settings to align mutual understandings. Also, the study clearly describes

the applied methodologies which have been proposed in various literature and widely applied in qualitative research.

Finally, confirmability or objectivity is an important aspect to be considered in qualitative research. Even if it is not possible to fully achieve neutrality and objectivity in qualitative research (Ritchie et al., 2013), several efforts were done in this study to enhance research confirmability. Firstly, this study aims to foster authenticity by ensuring participants make accurate representations of themselves (Yin, 2011). As anonymity of the participants and companies were guaranteed beforehand, the respondents can be confident speaking their minds and sharing holistic opinions about the topic. Furthermore, a conversational interview atmosphere was intended to maximize participants' comfort and flexibility. To ensure objectivity in data analysis, the development of systematic coding was done based on the theoretical framework to ensure consistency and was evaluated afterwards against the collected data to identify possible new codes. Moreover, comprehensive quotations collected from the interviews are included throughout the interpretation of the results to justify confirmability.

## 3.5 Limitations of research method

This section describes the limitations associated particularly with the research method of this study.

Firstly, although remote interviews for this study were successfully conducted, face to face interviewing is still a better option to maximize interactivity. Moreover, face to face interviews can enable the researcher to better establish connections and build relationships with the researched. Also, it's worth mentioning a drawback of remote interviews which is the dependency on the Zoom application and internet connection. If a technical issue occurs, it causes extra time to correct and disrupts the discussion flow.

Secondly, interview duration could have been longer than one hour to capture more in-depth information, however, this could also restrict the company representative's willingness to participate in the study. Longer interview duration as well as an addition of other types of data collection such as observation or written interview could have been utilized to gather more data and reduce the risk of relevant issues remaining unnoticed.

Thirdly, transferability of the study is limited as the sample includes only companies and representatives from Finland. A wider scope of sample selection to include companies from other countries and industries would likely offer more multidimensional results.

Furthermore, due to a small number of interviews, generalization of results is not supported. For this, an increased number of interviews or further quantitative research should be conducted. Additionally, in most of the cases the interviews were carried out with only one or two representatives from each company who represent a specific department/functionality. This restricted the diversity of opinions about the topic within the same company context.

# 4 EMPIRICAL FINDINGS

Thanks to a variety of case companies, it was possible to gain a broad understanding of approaches used by companies to handle the disruptions caused during the semiconductor shortage. Overall, the level of agility in the supply chain can be reflected throughout the disruption management, which is subject to various perspectives such as company's size, product complexity and ways of working.

This chapter presents the findings derived from the interviews with each case company. The chapter is divided into 6 subchapters. First, a brief introduction to each case company is provided, including a description of their supply chain. Second, the different impacts of semiconductor shortage on the case companies' performance are discussed. The subsequent subchapters follow the themes defined from the data analysis process, which describe the practices of the case companies in coping with the semiconductor shortage. In particular, the third subchapter provides insights into the proactive approaches to supply disruption management, including risk management and supply chain alignment. The fourth subchapter focuses on the findings related to post-disruption related to reactive responses, flexibility, recovery and learning. The fifth subchapter goes through other aspects needed throughout the disruption management cycle with a focus on company culture, strategic collaboration and IT capabilities. Finally, the last sub-chapter concludes the whole chapter by providing a summary of empirical findings.

## 4.1 Background of case companies

There are in total 5 companies who agreed to participate in this research. They operate in various industries in Finland whose organizational sizes range from medium to large. Understanding the role of semiconductors in product offerings as well as the supply chain operations of each case company helps analyze approaches of disruption management during the semiconductor shortage. As the companies' identity is kept anonymous in the thesis, each company will be identified using a nickname reflecting their specialization or industry.

The first company, **case "Telecommunications"**, is a global player in the secured telecommunications industry. Their business focuses on the production of telecommunication solutions including software applications, equipment, and services. The company employs more than 350 people in Finland, where the central supply chain is located. In addition, they work closely with other offices around the world to provide

products and services to distributors and end customers. The company manages its end-to-end supply chain processes including purchasing, customer services, warehousing, logistics, and exporting. Their manufacturing activities are outsourced. Many of the company's products are highly customized and require configuration of various components. The most critical product designs are done in-house and manufactured by subcontractors, while some other parts are purchased directly from suppliers. The company's products are based on electronic components entirely, thus there is a strong dependence on the availability of semiconductors.

The second company, **case "Measurement machinery",** operates in the industrial machinery manufacturing industry, which has around 300 employees. The main operations are based in Finland and specialized in production of systems needed for technological research fields. Their product design, manufacturing and warehousing are managed in-house, however, the alignment of supply chain processes is yet to be developed. There are many silo processes in the company that are managed by individual people/team, however the company is planning to build "pipes" that connect those silos and enhance the flow of goods and information. Semiconductors play a key role in the company's products and production activities. There are chips needed in both the company's own products as well as in components from suppliers. As their products are getting more advanced, more electronic intelligence and features are needed in control systems of machinery. Additionally, the increasing demand to build chip factories worldwide also has an impact on the company, as they use the same component needed in chip manufacturing.

The third company, **case "Electronic manufacturing",** is a provider of electronic manufacturing services that employs over 100 employees in Finland (headquarter) and Estonia (manufacturing site). Acting as a contract manufacturer, their offers include production of cable, printed circuit board and other electronic mechanism assemblies that can serve as part of large networks or end products of their customers. Having an advantage of a relatively small size organization, Case "Electronic manufacturing" believes that the key to their competitive advantage and success in supply chain operations is flexibility and delivery accuracy. Their supply chain is said to be very steady with buffer stocks and good supply channels. Even if the biggest business of the company is cable and wire products which are not directly related to semiconductors, there are also similar component shortages in those areas that the company considers relevant for this study.

The fourth company, **case "Security"**, specializes in electronic smart locking systems, which is fully dependent on semiconductor availability in electronics components. It has over 200 employees in the Finnish headquarter and other branches around the world. The company mainly does the product design and prototyping while most of the production is outsourced to Electronics Manufacturing Services (EMS) companies that are responsible for the purchases of electronic components and manufacturing finished goods. All the company's products heavily require electronic materials, for instance intelligent processors and other semiconductor parts, without which no sales can be made.

The last company, **case "Cooling"**, is a manufacturer of cooling system for buildings, which employs around 100 employees. It has in-house factory and outsourced warehouse in Finland. Their suppliers are mainly based in Europe. The company's production heavily relies on electronic components. Semiconductors are included in all of their products; thus, the worst-case scenario would be production stop in case of semiconductor shortage. The company benefits from their relatively small size, which offers a good level of flexibility.

## 4.2 Impacts of the semiconductor shortage

Companies started to see the impacts of the semiconductor shortage since the beginning of year 2021. This crisis came as a surprise which could hardly be predicted.

> *"This component shortage happened as a surprise for us, we haven't been through something similar in the past"* (Case "Telecommunications")

> *"We were caught up by surprise, so we did not have any practices or processes ready, we did not notice about the component shortage until it was too late"* (Case "Measurement machinery")

> *"I have never seen something like this in my entire career"* (Case "Electronic manufacturing")

> *"The supply chain operation is very challenging given that the shortage of electronic components was already occurring last year, and we had to suffer the consequences for that"* (Case "Security")

> *"I think no one was prepared for this crisis and it's still the same now, you never know which component will be missing next week"* (Case "Cooling")

Companies have been suffering from delays of components due to the semiconductor shortage. Materials have been difficult to source while lead time has been significantly increased during the crisis.

> *"Two years ago, for majority of our products, the lead time from call-off to finished good availability was 5 weeks (forecasted) and 12 weeks (non-forecasted). Now, because of the semiconductor shortage, the lead time has increased to 5 months (forecasted) and 1 year for non-forecasted products, because many components are having basic lead time of around 1 year"* (Case "Telecommunications")

> *"We have seen that there are limitations in many areas, some materials are very difficult to source. Lead time has been very long. Some supplier said that component availability would be within 2 or 3 years, and it has been very difficult situation"* (Case "Electronic manufacturing")

Also, the delays in component supply have a direct impact on customer delivery capabilities, because of the ripple effect as explained in chapter 2.1.2.

> *"The shortage delays our deliveries to customer delivery, which then delays their project rollouts"* (Case "Telecommunications")

> *"There are constant delays in incoming materials. And we are struggling to ensure that there are no delays in our customer deliveries but there are still delays here and there"* (Case "Measurement machinery")

> *"…we may send some products to customer for installation, but they cannot use it until we get the missing component"* (Case "Cooling")

Delays in customer deliveries also have an influence on customer satisfaction. As the semiconductor shortage affects the component supply globally, most of the interviewed companies receive understanding from customers for the delays in delivery.

> *"Some customers understand the situation and decide not to apply the contractual penalty even if they could and they want to find the best solution together with us."* (Case "Telecommunications")

> *"In general customers understand that materials are in shortage. It is not a big surprise for them"* (Case "Measurement machinery")

> *"At the moment most of the customers understand the global situation"* (Case "Cooling")

However, in some cases the customers' reaction has been quite pessimistic. Additional costs might arise for companies if contractual delivery terms cannot be fulfilled, meaning penalties need to be applied. As the impacts caused by the semiconductor shortage occurred quickly with high severity, it is difficult for some customers to understand the reasons behind the delays.

> *"Some customers were strictly looking at what the contract is saying, and some others were more flexible. This situation is difficult for some customers to understand why there is such sudden delay"* (Case "Telecommunications")

> *"At the beginning some customers were angry that we were not able to meet the promised delivery…"* (Case "Electronic manufacturing")

> *"…some customers think that they are special customers, so we have to arrange the supply somehow with prioritization" (*Case "Measurement machinery")

All the company representatives share the same thought that the semiconductor shortage has a significant financial impact. Supply disruptions caused extra costs in finding workarounds to continue production and deliveries. Direct costs were mainly from the purchases of components from the open market, which can be many times higher than normal.

> *"When material is not available from the original source of supply, we look around if there are any alternatives…But when global demand for these parts increased, prices*

> *also increased. From the brokers, the prices can be up to 50 to 100 times more expensive."* (Case "Telecommunications")

> *"…we were chasing individual pieces here and there that cost like a hundred time more expensive than before and still we had to buy those."* (Case "Measurement machinery")

> *"There are lots of additional component costs. For some customers we have agreed that we can use alternative channels and apply some additional costs."* (Case "Electronic manufacturing")

Besides component costs, there are indirect costs associated with the activities done in response to the component shortages. As mentioned by case "Security", extra costs are associated with preparing and preventing the shortage as more commitment needed to be made in the long term. For instance, extra costs can be incurred from keeping buffer stock, quality risk or technical planning.

> *"We have a much longer commitment to make in a long term… preparing and preventing the shortage cost us."* (Case "Security")

> *"We have increased our buffer stock, which costs more. We have also increased the parts as backup that we eventually did not use"* (Case "Cooling")

> *"There are also quality related costs. When buying parts from an open market and doing different workarounds, the quality risks ae getting higher."* (Case "Telecommunications")

> *"The use of alternative parts increased the cost of technical planning also because their structure has to be planned differently than regular parts."* (Case "Cooling")

The workload has also noticeably increased in companies. Additional hours were spent daily coping with the component shortage. This also results in increased costs for overtime work.

> *"During the crisis we need resources to follow up the situation daily"* (Case "Security")

> *There are also costs in extra effort. A lot of people were spending multiple hours negotiating things, looking for parts or trying to escalate topics"* (Case "Telecommunications")

> *"Something that we see every day is that the workload for purchasing has multiplied -- the workload it has gone up exponentially. The team needed to communicate with customers and check availability from suppliers on a daily basis"* (Case "Electronic manufacturing")

> *"…it's harder to get the confirmation for the delivery, so it takes lots of more time in the surveillance, following up and communication. Also, technical planning of alternative parts takes a lot more time."* (Case "Cooling")

The semiconductor shortage has clearly impacted companies in various ways. Sourcing difficulties, long lead time, increased costs and increased workload have been the common issues faced by case companies. In the next sections, companies' ways of working and approaches in coping with this crisis will be discovered.

## 4.3 Pre-disruption

This section describes the findings related to alertness and accessibility aspects of supply chain agility during the pre-disruption phase, which is divided into three parts. The first sub-section gives an overview of the case companies' approaches to manage supply disruption risks. The second part highlights how companies ensure alignment of their supply chain.

### 4.3.1 Supply disruption risk management

Being able to detect the shortages early is crucial in taking quick proactive actions to prepare for the crisis.

> *"Normal shortage situation comes and goes once in a while, but now this is a very serious one --- If we would have noticed this even 3 months earlier and acted properly*

> *then we could have bought those slots that we need for the next 2 years already quite easily. Now we are in trouble as we acted only when we saw delay from suppliers"* (Case "Measurement machinery")

The detection and preparation of the shortages also highly depend on other supply chain partners, for instance suppliers and subcontractors. Most of the companies interviewed receive information on a weekly basis from suppliers and manufacturing partners about component availability and purchase order statuses. During the semiconductor crisis, this is especially important to be up to date with the situation and plan workarounds.

> *"Our subcontractors are the ones who have the latest lead time in their system. We track the situation on a weekly basis and agree on action to solve."* (Case "Telecommunications")

> *"We discuss with the suppliers about the situation and the availability, and we receive warnings from our suppliers. They can inform us if something is happening in the market"* (Case "Electronic manufacturing")

> *"We receive information from both EMS and suppliers…They report on weekly basis to us the status component by component, they have a list which has their open POs and stock demand. We are able to check the basic information, but we don't yet have any clear picture of all the locations combined. So, the visibility to the full supply chain is still lacking."* (Case "Security")

Existing risk management practices at companies have been useful in preparation for the incoming shortages. Supply chain risk management is involved in different activities. In sourcing, having buffer stock, alternative component and alternative supply sources are commonly implemented by companies, as illustrated in table 4.

The possibility of having backup or multiple suppliers highly depends on the type of product. It is hard and more expensive to have multiple sources of supply for customized products.

> *"We have been depending on one single supplier for the production of customized components and the main reason is that it is so expensive to duplicate the supply that we cannot just bear it."* (Case "Telecommunications")

> *"Our product design needs certain processors from certain manufacturers that cannot be replaced with another one without R&D design projects."* (Case "Measurement machinery")

> *"Depends on component type and its functionality in the product. Sometimes it's not easy to find alternative suppliers, for example for processors"* (Case "Security")

*Table 4: Empirical findings: Risk management approaches in sourcing*

| **Approach** | **Illustrative quotes** |
|---|---|
| Buffer stock | *"We do set up buffer stock for our products. We also have raw material buffer stock for our supplier, we have buffer agreement they stock so that they can be used when we need."* (Case "Telecommunications")<br>*"For all of our components including electronics and mechanics we have required our EMS to build a buffer stock. They need to be prepared so that if there is any disruption in the supply chain, they would be able to manufacture still for a certain time."* (Case "Security") |
| Alternative supplier | *"For a lot of components, we have three or four sources from different manufacturers for the same part, and those were always helping in this situation"* (Case "Telecommunications")<br>*"We have tried to increase the buffer stock and at the same time in cases where there are alternative suppliers"*<br>*"…if component ends up in danger or shortage list, we contact other alternative distributors and try to find the same component from other sources."* (Case "Measurement machinery") |
| Alternative component | *"…and we have used also alternative components if possible and try to be proactive to find alternatives beforehand."* (Case "Electronic manufacturing")<br>*"…we do lots work with R&D regarding raw material availability and checking if we can use any alternative materials"* (Case "Security")<br>*"We have planned alternative ways of building our products by using alternative components, so that we are not depending on only one part, but we have different kinds of part that we might use"* (Case "Cooling") |

For companies whose manufacturing is outsourced, risk management practices are dependent on the contractual manufacturer's risk management activities. For example, case "Security" has been highly relied on EMS inputs for risk management. When their EMS foresees a risk, they are forced to react accordingly.

In addition, Modifications to product design has also been considered in case when no alternative supply can be found. It is, however, can be challenging depending on product complexity and cost constraint.

> *"If supply is totally dry out then we discuss with R&D if this component can be replaced with something else with small or big design changes"* (Case "Measurement machinery")
>
> *"…regarding shortage we do lots of alternative component searching but of course also product design changes…"* (Case "Security")

> *"The risk mitigation would be of course to have continuous re-design of product, to renew component portfolio…but it's up to the budget and possibility"* (Case "Telecommunications")

These approaches might work well in the regular supply disruptions. However not all of them can help solve issues caused by the recent global semiconductor shortage. For instance, stocks were consumed before buffer can be built and there has been no way to increase safety stock because everything available was used immediately (Case "Telecommunications"). Also, according to case "Measurement machinery", inventory optimization is no longer important during the crisis because they needed to pay everything needed to get the component in shortage.

### 4.3.2 Supply chain alignment

Having an aligned supply chain is necessary in maintaining agility and coping with component shortage. The case companies have different approaches to align supply chain processes. Firstly, sharing of resources is considered useful for aligning different supply chain activities.

> *"We align the tools and processes for demand planning globally… It does help in this kind of crisis especially when we have components that are share between different*

> *products. The manufacturing of product is also shared in such way that there is global subcontracted manufacturer who is in charge of producing technologies that have same customized components."* (Case "Telecommunications")

The use of information systems is considered to be crucial in supply chain alignment. Enterprise Resource Planning (ERP) systems can be used to manage end-to-end information flows and keep track with the latest status of different supply chain activities.

> *"It's very important to have ERP system. With our current ERP system, it's much more transparent and easier to understand how one process affects the other…in quotation phase the customer can already provide list of alternative parts and we save them in our ERP system, it makes thing quicker as we automatically know that this part can be replaced with these alternative materials. It helps when there is a shortage, then we look into ERP system and know that there is alternative."* (Case "Electronic manufacturing")

In addition, collaboration with other functions and having shared IT tools promotes information sharing and fosters decision making, which is essential in supply chain alignment.

> *"We have both internal meetings between supply chain functions and external meetings with suppliers to gather inputs for decision making"* (Case "Cooling")
> *"We also have a tool that is used together with R&D when it comes to component data, component availability and component life cycle management. In electronic component point of view, it is a very important tool to have knowledge in design phase, what is the status and availability of the materials in the market before deciding to use the component"* (Case "Security")

Some companies stressed the importance of having standardized processes in ensuring supply chain alignment and have been trying to build them.

> *We are in the stage of planning our processes for the operation, supply chain and procurement activities. We try to plan the to-be processes for the end of the year. Now shooting to near future with optimal processes and then implement those. With supply chain alignment we could have performed better during the component shortage."* *(*Case "Measurement machinery")

> *"During the past 2-3 years, standardization has been a real focus point in our company to make the processes a bit stiffer so that we can understand our common goals and priorities. We have common ways of working but it's still under development, so we still have quite a lot of hassles and confusion on what and how we are doing.*" (Case "Security")

> *"It's still a work in progress, but we are trying to build a new order intake process with sales so that we do not take in orders that we cannot fulfill"* (Case "Cooling")

In overall, being proactive in mitigating and preparing for the component shortages requires staying alert and having access to needed information. These are enabled by ensuring the alignment between different supply chain processes and parties. Having supply risk management practices in place helps companies to better react to the sudden changes caused by the component shortage and plan for future reactive actions.

## 4.4 Post-disruption

This section describes the reactive approaches taken by case companies during the happening of the semiconductor shortage. It is divided into three parts. The first part gives an overview of actions the companies have taken in response to the crisis. The second part further discusses the flexibility aspects in the case companies' supply chain. Finally, the last part of this section focuses on the recovery and learning points from the crisis.

### 4.4.1 Responses

Once the crisis has emerged and its negative impacts have become more server, companies were forced to react in several different ways. Table 5 summarizes the common approaches taken by case companies to response to the semiconductor shortage. As some approaches are implemented by several companies, only a selected number of quotes are listed in the table as examples.

*Table 5: Empirical findings: Reactive approaches to the semiconductor shortage*

| **Approach** | **Illustrative quotes** |
|---|---|
| Escalation and negotiation | *"The first option is to go back to the supplier and escalate the topic to refuse the postponement or request for improvement."* (Case "Telecommunications")<br>*"…we need to keep asking questions and keep pushing, and together with manufacturers we can figure out the problem and work together to improve the situation"* (Case "Electronic manufacturing") |
| Regular follow-ups | *"A method that helped during this situation is that we have had active communications with customers and kept regular meetings."* (Case "Electronic manufacturing")<br>*"A lot of information is received from suppliers by regular emailing and day-to-day conversations"* (Case "Cooling") |
| Purchases from open market | *"During the first months of the shortage, we used open market/broker in quite a lot so we can perform well towards customer"* (Case "Telecommunications")<br>*"We had to buy parts from open market and those costs more"* (Case "Cooling") |
| Buffer stock | *"We have modified the system parameter, increased safety stock level, increased order sizes, and compromised our inventory rotation"* (Case "Measurement machinery")<br>*"We have suggested customers to have buffer stock from us to ensure delivery accuracy during the shortage"* (Case "Electronic manufacturing")<br>*"For all of our components including electronics and mechanics we have required our EMS to build a buffer stock"* (Case "Security") |
| Alternative supplier | *"We also look into alternative dealers or suppliers"* (Case "Electronic manufacturing")<br>*"We proactively make additional purchases from local markets"* (Case "Security") |
| Product redesign | *"On some areas the R&D has activated product redesign."* (Case "Telecommunications")<br>*"If supply is totally dry out then we discuss with R&D if this component can be replaced with something else with small or big design changes"* (Case "Measurement machinery") |
| Demand management | *"We identify who are the customers that need the product first based on different criteria, for example contract penalty."* (Case "Telecommunications") |

| | |
|---|---|
| | *"We are telling sales what can be sold, for example, we can tell them not to sell some spare parts because we want to reserve those for the systems."* (Case "Measurement machinery")<br>*"In couples of occasions, we have had to say to EMS to produce this product and not that product, but they have been very short time solution"* (Case "Security") |

### 4.4.2 Flexibility

During the global semiconductor shortage when there is supply disruptions globally, companies were forced to enhance flexibility in different aspects to keep production and customer delivery on-going. The level of flexibility in supply chain operations was also discussed during the interviews.

In terms of sourcing, flexibility depends on the type of product. Customized or highly complex products require a specific source of supply that makes it hard to have alternatives.

> *"We have a lot of customized and non-mainstream materials. Thus, typically there is no backup supplier. We have been depending on one single supplier for the production of customized components and the main reason is that it is so expensive to duplicate the supply "*(Case "Telecommunications")

> *"Our products have not been designed in that manner that there can be optional suppliers. Product specification is designed with certain component from certain supplier."* (Case "Measurement machinery")

As there are extra costs incurred from purchasing components from alternative sources, flexibility in sourcing also relies on customers' support and trust.

> *"For some customers it has been agreed that we can use alternative channels and apply some additional costs. It is impossible to go through each product line and discuss prices with customer because amount of work is so much---when customers trust that we don't add additional costs than necessary, they give us freedom to decide, it saves time because we can focus on critical items and not go into too much detail."* (Case "Electronic manufacturing")

In production, flexibility can be applied in a way that when there is missing component, production can be flexibly modified to utilize other available materials. For instance, Case "Cooling" continued their production with other parts and delivered to customers what was available, while waiting for the missing component. However, companies whose manufacturing activity is outsourced have less control in flexibility, as they need to rely on the subcontractor. Subcontractors also have cost constraints to be flexibility, thus companies could be forced to bear the extra costs for flexibility

> *"We have been forced to support subcontractors in inventory cost and other types of costs that occur. Manufacturers are not flexible because financially they cannot offer too much flexibility. We ourselves cannot always be flexible in offering them financial support."* (Case "Telecommunications")

> *"…we also have obstacles with flexibility scalability because we have the supply chain with EMS-external companies. So, to have more flexibility we need to gain more visibility to the EMS supply chain operations."* (Case "Security")

Some companies have been also flexible when it comes to logistics/ demand fulfilment. Approaches include for example customer delivery prioritization (Case "Telecommunications"), being more inflexible towards sales by restricting what can be sold to customers (Case "Measurement machinery") and doing partial deliveries to customer (Case "Cooling").

Technical product planning and product redesign is also considered a critical flexibility aspect especially in case of component shortage. In one company, flexibility in engineering is part of the contingency planning, while in another this possibility is restricted by company culture.

> *"Our back up plan is to have alternative ways to build our product so we can use different parts for the same products, maybe some parts that are simpler and require less semiconductor. Those parts do not require so much new technology that is having component shortage, but still do the basic functions"* (Case "Cooling")

> *"…traditionally the company has not budgeted enough for the active maintenance / redesign of the products. Our company has traditionally more focusing on understanding the availability of components and making last-time purchases to stock*

> *so that we have enough stock to support product lifetime. This is quite risky. Active redesign/ maintenance of product would be safer option in product delivery perspective"* (Case "Telecommunications")

In overall, there are similarities and differences in approaches how companies react and response to the semiconductor shortage. They depend on the type of supply chain, product complexity as well as level of flexibility in supply chain operations. In addition, speed in action taking is also a crucial factor of agility, this will be further elaborated in sub-chapter 4.5 about company culture.

### 4.4.3 Recovery and learning

Recovery is part of the disruption management cycle where companies take needed actions to return operations back to normal. However, because this thesis was done at the time when the semiconductor crisis was still on-going, input about recovery was very limited. Almost all the companies believed that recovery had not yet started, as the situation of the global shortage has not improved.

> *"There was recovery in some component but then we faced new issues with new components all the time. So, in overall I would say that we have not been able to recover."* (Case "Telecommunications")

> *"We cannot talk about recovery because the crisis is still on-going, and nobody knows how long it still take and does it get better or worse. Until now we have been able to find alternative distributors, find individual pieces and survive a little bit more. But there is no guarantee that this way of working will carry us all the way through this component shortage. There might come a time when for some component the supply is just totally not available in the world anymore."* (Case "Measurement machinery")

> *"We have not been fully recovered. I think this year will still be very challenging. No one knows what will happen next"* (Case "Cooling")

Companies shared their views and understanding about the global situation of semiconductor manufacturing and supply. A full recovery was not expected this year, as it takes time and investment to increase semiconductor production capacity. In addition, as

new crises have emerged in the world, such as Ukraine war and lockdowns in China, it is unpredictable what kind of disruptions might happen.

> *"We know that in the world there is not enough capacity for the silicon material which is the basic for components. There are several on-going projects to build new factories in the US, Asia and EU and those investment takes couple of year. The estimation is that somewhere in half 2023 we should start to see positive trend on the recovery."* (Case "Telecommunications")

> *"Before this war in Ukraine, it started to look a bit better but now it is somehow getting worse again. Also, I'm expecting that the lock down in China will make it worse later this year. So, the situation goes up and down"* (Case "Cooling")

The semiconductor shortage has caused damage globally, however, it is also an opportunity for companies to rethink supply chain agility and transform their processes. Although the crisis is still on-going, the interviewed companies were able to share their experiences on what could have done better and what they have learned so far from the crisis. The common aspects of what could have been done better include being better alert about the situation to making quick decisions. In addition, the need for more flexibility (in Case "Telecommunications") was also mentioned.

> *"The crisis pins point the need to be alert and react early enough. If you miss the first trend, for this case it was one and a half years ago, then you are in trouble for the next 2 years. So, it's important to be alert and just in case make good decisions and buy components for the next years into stock and pay a lower price. This was what we could have done, now as it was not done, we will be suffering for the next 2 years being on continuous risks to stop the production, spend time daily to follow the situation, and pay for components tens to hundreds time more."* (Case "Measurement machinery")

> *"We could be even more proactive in responding to the crisis, but on the other hand we also understand that the resources are limited. If we had known that this shortage situation would last that long, we would have increased resources in purchasing. We could have been more active in meeting with customers to discuss the situation."* (Case "Electronic manufacturing")

> *"The main thing that could have been done better is the active product maintenance and redesign. But our culture has not allowed that, it's more like making a product and trying to keep it alive as long as possible with last-time purchases of components to stock."* (Case "Telecommunications")

As mentioned earlier, the semiconductor shortage has significantly increased the amount of workload in the supply chain. As a result, a need for atomizing processes arises.

> *"We had quite a lot of hassles around our processes and tools that we are using. During the crisis we need resources to follow up the situation daily and time should not go to manual work with no value creation. The focus should be on crisis management. So, this year we have been forced to improve our data visibility and data automation as well so that we don't do everything manually on excel files."* (Case "Security")

Moreover, companies have learned to deal with the crisis and confirmed that they have performed better now than at the beginning when it started. Proactivity has been improved as companies now understand which components are at risk and pay close attention to improving availability of those. Also, procedures have been established to foster quick reactions to disruptions.

> *"Previously we lacked even the knowledge of what are the risky components but now we have that visibility and know what the next steps and potential risks are. At least with the knowledge that we gained we know to focus on the right components"*
> (Case "Security")

> *"I think when this crisis goes on and on, we will becoming more and more agile all the time. When it started, we were only following up and waiting for parts. But now we are able to react faster, we proactively search for parts and put them into development even if we don't eventually need them. We have more procedures that we react faster, we know what to do regarding order intake and how to inform customers"*
> (Case "Cooling")

## 4.5 Other aspects throughout the disruption management cycle

Supply chain agility in disruption management is also driven by other aspects needed both before and after the disruption. This section provides the findings about these, which are presented as three sub-sections: company culture, strategic collaboration and IT capabilities.

### 4.5.1 Company culture

Company culture has several implications on agility during the semiconductor shortage. Having a culture of change is needed in achieving flexibility, a core aspect of agility. During the semiconductor shortage, it is crucial to make quick decisions especially in purchasing because component availability is highly limited. Due to the global scale of this crisis, there is a big competition in component sourcing globally. For instance, Case "Telecommunications" has missed out several materials due to slow purchase approval process. Despite having received prompt approval from its client for purchasing, Case "Electronic manufacturing" missed part as it was quickly gone. Also, and there were offers that lasted only a few hours (Case "Cooling").

The case companies addressed several implications of culture during the disruption management process, as illustrated in table 6. Firstly, flexibility in decision making is considered an advantage by companies, which is needed to react fast to sudden disruptions caused during the disruptions. Secondly, employee empowerment is valued especially when the amount of workload has increased tremendously during the crisis. On the other hand, too much freedom might also slow down decision making process, there is a need for authority to facilitate fast and bold actions during the crisis. In addition, since big decisions are usually made by the high-level managers, it is important for companies to have positive and supportive top management. Some of the interviewees expressed their satisfaction with their company's management support and believed that it helps during the semiconductor crisis.

*Table 6: Empirical findings: Implications of company culture on agility*

| **Approach** | **Illustrative quotes** |
|---|---|
| Flexibility in decision making | *"We are not a too big company so there is not too much hierarchy so we can make decision quickly" (*Case "Cooling")<br>*"Internally we are very flexible in decision making, for instance it's easy to send a message to our CEO asking for purchase order approval"* (Case "Security") |

| | |
|---|---|
| Employee empowerment | *"Nowadays we have given our purchasers more freedom to be flexible and make decision by themselves. It helps a lot in their job because there are so much to do. The less they have to worry about authority to make decision, the better"* (Case "Electronic manufacturing")<br>*"It's helpful when I have free hand to make decisions"* (Case "Cooling") |
| Authority | *"Our company is flexible in a way that there is good intent of empowerment but it's not clear for people what can be decided and what's not. When more and more things are brought up for escalation manner, it gets frustrating and stressful, and decision takes even longer. Now as the company has grown, it needs processes and authority. Because when there are layers in between it takes time for things to escalate up, then things change when they are cascaded down ---knowing what can be decided and on what level is important."* (Case "Measurement machinery") |
| Supportive top management | *"Positive leadership culture would be an essential part of making us alert and react quick enough, so not only alert but actually do something with that information. People are afraid of making mistakes because of negative leadership. They would think that it's better not to make decisions and we end up waiting lots of time. So even if we would be alert, people might not react because they are afraid of speaking their mind"* (Case "Measurement machinery")<br>*"The management is really interested in knowing the up-to-date data about any supply chain risk and they are very happy to help however they can with the difficulties. Everybody understands the situation, what it requires when there is an issue, for example to have quick and solid decision making. In that sense it's a smooth and easy process in our company to deal with issues and get the results"* (Case "Security")<br>*"We have tried our best to support our purchasing team and to make them feel that their work is very much appreciated. This is very important because it is a difficult situation and without them, we would be in much bigger trouble"* (Case "Electronic manufacturing")<br>*"The management have invested a lot in production and warehousing to mitigate the issue"* (Case "Cooling") |

| | |
|---|---|
| | On the other hand, it is not always easy to make the management understand the situation.<br>*"Decision has not been very efficient. We have been trying to explain the situation to top management for one year, there was a lack of interest and focus. Somehow, it's difficult to get the message through. We could have communicated better but sometimes even if we try, the person who is receiving the message still thinks it's not their business"* (Case "Telecommunications") |

Feasibility for a culture of change depends on company size. As learned from the interviews, small companies (such as Case "Electronic manufacturing") tend to have a much better flexibility than larger companies (such as Case "Telecommunications").

> *"We have a weak change culture. The technology used in our products has a long history. When the big players move to the next generation of component, and we are staying there for a long time. It becomes the problem when we become out of the mainstream, and we are behind those forerunners."* (Case "Telecommunications")

> *"The flexibility has been in our DNA. As we are still a relatively small player, we can be agile and flexible and it's one of our competitive advantages"* (Case "Electronic manufacturing")

The culture has changed during the crisis due to the pressure from component shortage and increased costs. In one company, the change was positive while in another, the change has become a barrier to agility.

> *"In the past, they used to search for the best components in terms of price and quality and stick to that component. Now the culture is more flexible, so we are accepting different kinds of component and more ready to take them into production"* (Case "Cooling")

> *"Decision making has changed during the crisis. Last year it was much more flexible and reactive. Whereas now, as the extra costs have gone up, the management have become more conservative. We have a weekly procedure where we combine weekly extra costs as a proposal and need to clearly make justification. Depending on the costs there is one or two steps of approval after that."* (Case "Telecommunications")

### 4.5.2 Strategic collaboration

Success in managing supply disruptions relies on the collaboration with other supply chain partners and functions, both internally and externally. The level of collaboration varies case by case, mainly based on the type of product. If the product is customized, external stakeholders are more involved in supply chain activities.

> *"Customers are of course involved in product planning because many of our systems are engineer-to-order, so there are lots of communications with customers. They are in planning and design processes"* (Case "Measurement machinery")

> *"Collaboration also depends on the product. If it's a simple product that is commonly used, then not so much collaboration is needed. But if it's custom-made, tailored specifically for us then it's important to have regular follow-ups and meetings with suppliers" (*Case "Security")

Collaboration with internal functions is needed to come up with solutions to issues caused during the crisis. Typically, when it comes to component shortage, supply chain core functions (such as purchasing, production and logistics) need to collaborate with product-oriented functions (such as R&D and engineering) to discuss component criticality and identify approaches to ensure product availability.

> *"We work with R&D/component engineers on a daily basis in close collaboration. Regarding shortage we do lots of alternative component searching but of course also design changes"* (Case "Security")

> *"The most important functions like purchases, production, technical design and product data management are having meetings regularly to plan alternatives so that we can react faster to all kinds of changes to the market"* (Case "Cooling")

Trust is also considered an essential factor in building good relationships and collaborations. As a supplier, companies can proactively offer extra help to customer, for example, Case "Electronic manufacturing" has utilized its supply channel to help customers find alternative sources.

> *"Trust from customers is also important. If they trust us and give us a free hand, then it's a big help for us to make smooth decisions. Trust helps tremendously and*

> *customers who trust us quite often have long term relationships with us and they know that we are trustful."* (Case "Electronic manufacturing")

> *"In some cases, we have had very good supply channels. For example, we have a component engineer who has good relationship to sources in South Korea and thanks to that we were able to manage difficult issues. And we also offered this help to our customers."* (Case "Electronic manufacturing")

Strategic collaboration can be helpful in different ways when there is component shortage. For example, big customer names can be utilized to increase purchasing power and make an impact on suppliers.

> *"In some cases, we have lots of customers who have strong purchasing power. We recently had meetings with a large supplier and alone we cannot really affect their deliveries. But we had one big customer that we took into the meeting and together we were able to increase our purchasing power and improve delivery time. So, using the power of customer is possible affect supplier delivery capability"* (Case "Electronic manufacturing")

Having knowledge and understanding about partners has been helpful during the crisis, according to examples mentioned by Case "Cooling".

> *"We have been working with many suppliers for many years, we know each other quite well and that of course helps a lot. Our supplier usually knows that we never have a problem with payment. So financial security helps to create trust"* (Case "Cooling")

> *"We have tried to create a better informing process for our sales so that they can keep our customers better informed. Many of our customers work on construction sites so if they get the information too late, they have all the resources there doing nothing so it's costly"* (Case "Cooling")

On the other hand, external partners can lack the motivation to act proactively when shortage does not directly affect them.

> *"We are basically covering all the extra costs, I think it's a concern, because from the subcontractor's point of view the process is easy. There is not much pressure on them*

> *to proactively improve the situation or take action to calculate risks---So they don't order anything extra, and they don't order anything in advance. If anything fails, we have to pay all the extra costs, for them it doesn't really matter"* (Case "Telecommunications")

Moreover, the semiconductor crisis has offered new opportunities to make impacts, collaborate and build relationships with partners. When facing component shortages, customers have started to realize the need to implement backup plans. The limited sources of supply around the world also encourage companies to work more closely with other further supply tiers within the supply chain.

> *"With some customers we have tried to bring in buffer for years and they said that they don't need and can wait for few more weeks. But now it has become a bigger problem and they realized that they should the buffer. So, the situation opens their eyes."* (Case "Electronic manufacturing")

> *"This crisis also brought us closer to the manufacturers. Before this, manufacturers tend to push customers further away in their supply chain and there is usually a middleman (a distributor or some representative) who sells you the parts. Now we have had escalation discussion directly with different manufacturers, I feel like we have gotten a bit closer and got more responsive feedback from them."* (Case "Telecommunications")

### 4.5.3 IT capabilities

Decision making and collaboration do not rely only on human resources but also IT capabilities. IT tools and systems are needed to enhance visibility to different supply chain operations, increase alertness and responsiveness during supply disruptions.

The companies interviewed have an ERP system in place to manage daily supply chain operations. ERP systems ensure the smooth flow of goods and information, which are crucial in keeping business activities on-going.

> *"We also have our ERP system that supports purchasing quite a lot. As the workload has increased so much during the component shortage that without a good system it would not be possible to work."* (Case "Electronic manufacturing")

However, using ERP system alone is not enough to gain the latest information in a timely manner and increase responsiveness. Companies expressed interest in having additional IT tools that can be beneficial in case of component shortage. For instance, case "Measurement machinery" thought that IT tools used to analyze spending, supplier capability and relationships would be useful. As the dependency on external partners limits operational flexibility and accessibility to real-time information, it is essential to implement IT solutions that provide end-to-end visibility to supply chain and reduce manual processes (Case "Security"). Case "Cooling" also agreed that having extra tools to follow up the semiconductor shortage should be considered.

Other IT solutions have been implemented or planned in some of the case companies to support supply management. They are considered potential in helping companies cope with the semiconductor shortage. For example, a third-party database is utilized in case company "Telecommunications" by component engineers to generate life cycle analysis and availability information for commercial components, which also gives a big picture about the component situation during the shortage. Similarly, case "Security" also has a tool that is used together with R&D for managing component data, component availability and component life cycle. The company also confirmed the role of R&D-related tools in gaining information about status and availability of components in the market, which is crucial for procurement and production-related decision makings.

Besides, a purchasing software has been considered by case "Electronic manufacturing", which is aimed to automize the quoting process by automatically providing components' prices and availability information. The company also believe that having such software would significantly help reduce workload during the semiconductor shortage. Furthermore, some IT projects have been planned by (Case "Security"). One is a planning tool needed to gain long-term visibility to component demand, another one is sourcing tool which utilized for product pricing. Also, with an aim to increase visibility to external partner's supply chain operations, case "Security" has also been planning to build a supplier interface to foster active communications between with the EMS regarding open orders and material flow.

## 4.6 Conclusion of findings

The empirical findings of this study provide answers to the thesis research sub-questions. The semiconductor shortage has had various impacts on companies' operational and financial performance. Supply shortages caused by this crisis have resulted in multiple difficulties in sourcing, production, and customer delivery due to component unavailability and increased lead time. Direct and indirect extra costs associated with preparing and reacting to the component shortages increase the financial burden on companies. Limited component availability forced companies make prioritization for order deliveries, which caused delays in delivery to some customers. Although most customers understood the situation, companies still faced the risk of penalties for breach of contract. In addition, the amount of workload has significantly increased as extra effort was spent on escalating finding and escalating workarounds to deal with disruptions. At the time this study was done, the shortage is still on-going and might worsen due to other parallel incidents happening around the world.

Due to the severity of this crisis, companies had to take proactive and reactive approaches to manage disruptions while reducing negative impacts and ensuring business continuity. The semiconductor shortage is seen as an unpredictable crisis that gave no chance for companies to detect and prepare well enough. Thus, existing supply risk management and mitigation practices were found helpful in coping with the semiconductor shortage. According to the findings, the most common practices adopted by companies are buffer stock, alternative suppliers, alternative components, and product design change. The feasibility of these approaches depends also on product complexity as well as dependency on other external supply chain partners. Moreover, the alignment of supply chain processes is important in managing disruptions, which is supported by various factors such as resource sharing, close collaborations as well as ERP system. In facing the negative impacts of the semiconductor shortage, companies have been reactively following-up the situation, looking for alternative components and suppliers, and prioritizing customer deliveries. Recovery has not been a focus in this study, as the global component shortage is still on-going. However, companies have been able to learn from the disruptions so far and improved their ways of working along the crisis.

Agility plays a key role in successful disruption management during the semiconductor shortage. Active information sharing, follow-ups and collaborations are needed in increasing

alertness and accessibility to changes in supply. The case companies have worked closely with their supplier and/or subcontractors to gain visibility into component availability. Flexibility in supply chain activities is considered essential in the implementation of workaround plans and responding to sudden changes. Flexibility and speed in decision making is required to capture the best opportunities during the crisis, as there is intense competition between companies to obtain the same shortage component. Efficient decision making is driven by a culture of change which fosters empowerment and adaptation. Finally, IT tools and systems have been utilized to manage operations during the crisis and new IT solutions have been planned in some companies.

# 5 DISCUSSIONS

This chapter discusses the key findings from the perspective of the theoretical framework that focuses on supply chain agility in disruption management. The discussions focus on analyzing the empirical findings and comparing them to the reviewed theories. This chapter is divided into three main subchapters. The first subchapter discusses the impacts of supply disruptions in the context of the semiconductor shortage. The second subchapter focuses on approaches to manage supply disruptions. Finally, the last subchapter analyzes the implications of supply chain agility in supply disruption management.

## 5.1 Impacts of supply disruptions

The global semiconductor shortage has caused major disruptions in the supply of electronic components, which have several negative impacts on companies' performance. The interviewed companies viewed the semiconductor shortage as an unpredictable event that has not happened earlier. Such 'low frequency, high impact' incident has been said to massively disrupt the regular supply and demand fluctuation (Ivanov & Dolgui, 2020; Cai & Luo, 2020).

As Hendricks and Singhal (2003) state, supply disruption resulting from component shortage increases lead time and interrupts production activities, which could lead to inability to fulfill customer demand. Most of the companies interviewed confirmed that component lead time has significantly increased from their suppliers, which caused delays in final product manufacturing and deliveries to customers. According to some companies, the lead time has increased exponentially, from a few weeks to months and even years. This reflects the theory of the ripple effect, which is known as the propagation of negative impacts from upstream further downstream in the supply chain (Dolgui et al., 2019). Also, companies confirmed the increased vulnerability to disruptions in case of single sourcing, lower safety stock or lack of backup plans, which is in line with Dolgui et al. (2018)'s identified reasons for the ripple effect.

Financial impacts from the component shortage, according to Hendricks and Singhal (2003), can be seen from sales loss and increase in operating costs occurred from inventory, sourcing and resource workload. Although the impact on revenue was not specified by the case companies, all of them agreed on the fact that there has been a noticeable increase in operating costs during the crisis. These costs are associated with various factors such as

expensive component prices from open market and increased inventory costs for buffer stock which are in line with the study of Ishak et al. (2022).

Additionally, Hendricks and Singhal (2003) indicate that costs can be incurred by supply disruptions due to an increase in overtime hours, which was confirmed by the empirical findings. What arose from the interviews that was not covered by the theoretical framework was semiconductor shortage's impacts on workload. In particular, some interviewees mentioned that the workload in supply chain has significantly increased, as more time were spent on escalating issues, finding alternative components and suppliers, price negotiation or technical planning. The extra tasks caused during the semiconductor shortage does not only increase working hours but also reduce productivity in other regular daily operational activities.

Moreover, company's credibility and customer satisfaction might be affected during the semiconductor shortage as companies are forced to make prioritization between customers (Tomlin & Wang, 2011). Due to the component shortage, most of the companies interviewed faced an issue in fulfilling customer deliveries. While most of their customers have understood the shortage situation and accepted the delays, some others insisted on following the contractual terms with penalty pressure.

As per the companies interviewed, the situation with the semiconductor shortage has not improved and is expected to continue still to next year. Thus, it is important to understand the aspects of agility in the supply chain and how they can be utilized to cope with the semiconductor shortage. As per Ishak et al.(2022), maintaining an agile supply chain can help companies to anticipate risks, implement contingency plans, response in a timely manner, and recover back to normal operation.

## 5.2 Agility in disruption management

This section discusses the practical approaches used by the case companies during the semiconductor crisis. The agility perspectives in these approaches are compared to the theoretical studies, which will be presented under three parts. The first part describes the proactive approaches associated with the mitigation of and preparation for disruption, which are linked with the alertness and accessibility elements of supply chain agility. Second, proactive approaches related to flexibility and speed in responding to the crisis are explored. Finally, other supporting approaches including company culture, decision making, strategic

collaboration and IT capabilities throughout the whole disruption management cycle are discussed.

### 5.2.1 Proactive approaches

Pre-disruption phase in the disruption management cycle includes proactive activities aimed to mitigate the negative impacts and prepare for the disruption event (Behdani et al., 2012; Harrison & Johnson, 2016; Hosseini et al., 2019). As mentioned in the empirical findings, the semiconductor shortage is considered to be an unpredictable event for many companies. Thus, direct mitigation and preparation for this crisis was almost impossible. However, by having existing risk mitigation practicalities in place, companies were able to survive during the first months of the shortage and make further workaround planning to response to the crisis.

It is essential for companies to understand the potential risks of disruption and have appropriate mitigation strategies (Chopra & Sodhi, 2004). Approaches to mitigate supply disruption in academic literature, shown in table 1 in chapter 2.1.3, are in practice applied by the case companies. Companies have had buffer stock to be used in case the main components are delayed. Some others have been actively making sure that there are alternative sources of supply for critical components. Production has been made flexible in a few cases so that alternative parts and design changes can be utilized. These approaches vary depending on characteristics of the supply chain and product complexity. For instance, in a supply chain where manufacturing activities are outsourced, the mitigation strategies for production strongly depend on subcontractor's capability. Also, highly customized and complex products might cause difficulties in finding alternative resources or change product design. Having risk management practicalities could temporarily help companies to cope with the semiconductor shortage, however due to the severity of this crisis, it is important to stay alert about the current situation and gain accessibility to information for quick decision making.

Alertness and accessibility are crucial during the pre-disruption phase to better detect the disruption and organize resources (Behdani et al., 2012; Kim & Zhao, 2021). End-to-end visibility to the supply chain activities is essential, which can be achieved through regular information sharing and supporting IT tools (Stecke and Kumar, 2009). The case companies stay up to date with the component availability and delivery schedule through regular information exchange with suppliers and manufacturing partners. End-to-end visibility is

more challenging to gain for companies whose production is managed by subcontractors. As Chen et al. (2019) state, preparation for disruption should involve access to accurate real-time information to predict the impacts and make decisions. This was confirmed by case companies that input from external supply chain partners are crucial in facilitating internal planning and decision making, as well as in ensuring timely and accurate communications to customers.

Furthermore, agility in the pre-disruption phase is driven by operational alignment of actions and interests (Gligor and Holcomb, 2012) which is needed to enhance timely accessibility to information. As highlighted by Braunscheidel & Suresh (2009), internal and external process integration is important to ensure alignment, which can be supported by information Zhou et al. (2018). Most of the interviewed companies use ERP system to manage and align supply chain activities, which is found also useful during the semiconductor shortage for ensuring information flow. Aligned with Tse et al. (2016), the interviewed companies confirmed the importance of alignment between supply chain resources, tools and processes to foster external learning and better cope with component shortage. Moreover, some companies highlight the need for establishing standardized processes and ways of working that can enhance supply chain alignment during the crisis.

### 5.2.2 Reactive approaches

As identified in existing literature, once the crisis has occurred companies enter the post-disruption phase where reactive approaches are needed to response to the disruptions and facilitate recovery. Flexibility and speed are the agility dimensions (Gligor et al., 2013) that drive the appropriate responsiveness to the sudden disruptions driven needed to reduce consequences.

Timely response to disruptions requires resource allocation, active information sharing and collaboration (Behdani et al., 2012; Kim & Zhao, 2021). The interview findings confirmed this theory. During the semiconductor shortage, companies have followed up the situation on a daily basis with suppliers and received immediate information about potential delays. Internal collaboration has been facilitated through regular meetings between different functions to analyze the situation and make decision on reactive actions. Moreover, it has been emphasized that active communication with customers is essential to ensure common understanding, enhance flexibility in delivery and increase trust. As not all customers understand the severity of the semiconductor shortage, active information sharing

and status update with customers are required to maintain satisfaction while reducing the financial risks of not fulfilling the contractual agreement. Ensuring activeness comes with extra time and effort, the case companies have also highlighted a noticeable increase in workload for supply chain employees during the semiconductor shortage. This suggests that companies should pay attention not only on company performance and customer satisfaction but also employee well-being during this kind of crisis.

Adoption and implementation of contingency plans is crucial during the post-disruption phase (Stecke and Kumar, 2009). The literature review has shown different approaches to reduce the negative impacts of disruptions such as having safety stock, multi-sourcing, or backup production site (Sheffi and Rice, 2005; Ivanov et al., 2017). Effective implementation of these approaches requires flexibility which, according to Sheffi and Rice (2005), presents in sourcing, production and distribution. The findings from case companies confirmed the practicalities of these theoretical suggestions. All the interviewed companies have existing supply risk management practices, as covered in the previous sub-chapter, that are useful during the disruption. Having buffer stocks of some materials helped companies to survive when sudden component shortage took place. As the situation aggravates and safety stock was no longer enough to fulfil demand, companies have had to utilize sourcing flexibility - actively looking for alternative sources of supply and paying much higher prices for materials from open markets. Flexibility in production is quite limited at companies, as there is no opportunity to increase production capacity, a production flexibility aspect suggested by Sheffi & Rice (2005), due to cost constraint and dependency on external subcontractors. Flexibility in distribution can be reflected from the demand management enabler of agility. Two approaches suggested by Tomlin and Wang (2011) are product switching (suggesting customers to accept alternative product that are not in shortage) or rationing (strategic allocation of supply among customers). While product switching was not found from empirical findings, some case companies did manage customer demand by limiting what can be sold and prioritization during the semiconductor shortage. This is also aligned with Sheffi and Rice (2005)’s suggestion about using prioritization to allocate supply, considering different criteria such as profitability, costs and long-term relationship criticality. In addition, Braunscheidel & Suresh (2009) address the importance of flexibility in product design and engineering in ensuring agility. Depending on product type and complexity, the companies have considered making changes in product design to exclude

components that are in shortage. Besides the dependency on product characteristics, active product redesign has been thought to be driven by organizational culture of change.

As stated by (Braunscheidel & Suresh, 2009), supply chain agility highly depends on its other external partners. This was learned from the empirical findings. The level of flexibility in some case companies relies on suppliers/manufacturers and customers. When production is performed by an external party (subcontracted manufacturer or EMS), companies share that they have less control over the flexibility of manufacturing and even sourcing as the partner is also responsible for purchasing components. Gaining full visibility to external partner's supply chain is not easy given that processes and systems are different between companies. In customer perspective, it was found out from the empirical study that flexibility in decision making is enabled by trust and good relationship with customers. In some cases, customers' approval is needed for actions taken during the semiconductor shortage such as purchasing from alternative sources with higher prices or increasing buffer stock. Furthermore, flexible customers who understand the situation and accept changes in demand fulfilment are a great help for companies to manage supply disruptions.

Recovery is the last phase of the disruption management cycle aimed to return the supply chain back to normal operations (Braunscheidel & Suresh, 2009) and avoi long-term negative impacts (Ivanov et al., 2017). At the time this study was conducted, the semiconductor shortage was still on-going and therefore, companies have not implemented recovery activities. However, the reactive approaches taken by companies contribute to future stabilization and reduction of negative impacts. For instance, emergency purchases from alternative resources and increase of buffer stock were implemented by companies to ensure product manufacturing, as proposed by Chen et al. (2021). Furthermore, Chen et al. (2019) emphasizes the importance of learning during the post disruption phase in enhancing responsiveness through re-designing supply chain and reforming disruption management strategies. According to the empirical findings, case companies have so far gained valuable lessons from the crisis based on which actions have been taken to improve responsiveness. For example, companies have become more proactive in identifying critical components which are in shortage and knowing what reactive approaches to implement. In addition, the crisis has forced companies to establish more agile procedures in order to react faster when disruptions happen.

### 5.2.3 Supporting approaches

As discussed in the literature review, there are other aspects that have implications on supply chain agility during both before and after the disruption, which are: company culture, strategic collaboration and IT capabilities. They can either act as a proactive or reactive approach to foster agility.

**Company culture** is emphasized by Sangari et al. (2014) to be the dominating enabler of supply chain agility**.** It drives a firm's willingness to absorb external information and adapt it into company culture can improve supply chain agility (Russell, & Swanson, 2019). Culture of change has been defined to be a proactive enabler of agility (Humdan et al., 2020) which is needed during the pre-disruption phase, however, the empirical findings of this study have confirmed that it also has a key role during and after the disruption. The findings also align with Sangari et al. (2015)'s emphasis on the importance of change culture in enhancing the necessary competencies and capabilities for agility. Culture of change was considered essential to facilitate active product redesign, which allows for more flexibility in sourcing and production when there is component shortage. Furthermore, having a culture of change made it easier for companies to learn about the supply risks and adapt their processes or create new procedures to enhance responsiveness to disruptions. Companies who are more open to changes also have a more efficient decision-making process. Small firms typically have more a relaxed, flexible culture that enables freedom in decision making and quick reactions to changes, while larger companies have more complex requirements for change approval. Due to the increased workload needed for situation escalation and follow-ups during the crisis, freedom in decision making is considered helpful to speed up processes. However, too much freedom and flexibility were also considered not ideal for coping with issues during the semiconductor shortage, especially when it is not clear what can be decided. Findings from one case company have proved the need for more authority and structured practices in decision making.

**Management support** plays a key role in creating and maintaining a culture of change (Christopher & Peck, 2004) while allowing for informed decision making, increased flexibility and collaborative relationship among supply chain partners (Barve, 2011). According to the findings, supportive top management is seen as an important factor in dealing with the crisis. During such a difficult time, the management's commitment, focus and understanding of the situation smoothens decision making process and fosters flexibility. As mentioned in earlier theories, quick actions are required in response to disruptions

(Behdani et al., 2012; Kim & Zhao, 2021). This is true in the practice of this crisis, when many companies globally are searching for some kinds of component that are in shortage. As pointed out by the case companies, fast reaction is crucial during the semiconductor shortage as components became unavailable very quickly and offers could last only for a short period. Thus, complicated decision making, and budget approval process is considered a barrier to agility. Also, Agarwal et al. (2007) emphasize that supply chain managers should adopt strategies that promote process alignment and better use of IT tools. As learned from the interviews, some case companies' management have made investments in increasing supply chain capacities and adopting new tools to support daily operations. Furthermore, what was note covered in previous theories is the role of managers in ensuring employee well-being and motivation during supply chain crises. As pointed out in the practical findings, it is important that employees have enough empowerment, guidance and receive recognition for their contributions.

Earlier theories also suggest that **strategic collaboration** between different internal and external supply chain partners are essential for agility, which is enabled by high level of information sharing and trust, as well as collaborative work and joint planning (Lee, 2004; Lin et al., 2006; Agarwal et al., 2007; Braunscheidel & Suresh, 2009; Gligor et al.,2013). As customers and suppliers are the important sources of information contributing to the decision-making process during disruptions (Jajja et al., 2018), firms need to collaborate closely with these partners to keep up with the latest market information (Tse et al.,2016). In accordance with these theories, the findings prove companies' practices to have regular follow-ups with external partners and internal functions to keep up to date with the situation, analyze risks and make quick decisions. Active communication with customers about product availability and delivery schedule was also implemented by companies to ensure transparency, increase trust and flexibility, which confirms Sheffi & Rice (2005)'s suggestion. What is furthermore considered crucial from the findings is having trust with partners. Companies considered trust a highly valuable aspect in collaborating with partners and improving flexibility and responsiveness, as also suggested by Barve (2011).

Besides, Braunscheidel and Suresh (2009) highlight the role of a market-oriented (the knowledge about customers, suppliers, and interoperations) and learning-oriented (the focus on learning commitment, open-mindedness and common vision) culture in ensuring supply chain integration needed for achieving agility. These were referred by the authors to as strategic orientation, which is a reactive enabler of agility. According to the empirical study,

having knowledge about supply chain partners is confirmed to be essential in building strong relationships and fostering collaboration. For instance, understanding customers allows for better demand fulfillment considering customers' specific circumstances. Similarly, knowing the suppliers makes it easier to build trust and facilitate information sharing. Moreover, companies have become more open to changes and improvement during the crisis. For example, more flexibility in sourcing has allowed us to use alternative sources of supply and alternative components when there is shortage. Also, new procedures and tools have been planned to improve reactiveness to disruptions.

As a supplier, companies can proactively offer extra help to customers, as in the example given by case "Electronic manufacturing" where they helped customer to find alternative resources for components that are not supplied by them. This example reflects Sheffi and Rice (2005)'s suggestion that relationship with customers can be strengthened by helping them find new sources of supply and validate alternative suppliers. Strategic collaboration can also be utilized to increase purchasing power, for instance, involving their big customer names in the negotiation can make an impact, as learned from the findings. On the other hand, as a customer, it is not always easy for companies to have an influence on suppliers/ subcontractors. It has been found from the empirical study that companies usually have to bear all the extra costs, which give no incentives for suppliers to be proactive in offering extra help. This calls for a need to implement strategies that increase suppliers' willingness to share risks and monitor their resources during unusual or disruptive circumstances, as proposed by Jajja et al. (2018)

Last but not least, **IT capabilities** in supply chain are crucial for enabling a fast collection and sharing of information across functions and partners (Alzoubi & Yanamandra, 2020). IT solutions are useful in both the pre- and post-disruption management processes as they increase visibility that support decision making (Chen et al., 2019). ERP system is among the common tools suggested in academic literature as a core supply chain system used to manage end-to-end flows of goods and information (Baryannis et al., 2019). ERP system is in place at all the case companies and has been confirmed to hold a key role in ensuring on-going operational activities during crises. Besides, as indicated by Ivanov and Dolgui (2021), data-oriented digital capabilities are needed in both proactive planning activities as well as reactive practices. Some companies have planned or implemented other IT tools and practices in addition to the ERP system for better supply management. For example, some types of tools suggested in the findings are sourcing software to manage

pricing and find suppliers, interface to manage relationship with external partner's system, R&D-oriented tools for component management as well as analytics capabilities through online third-party database. In overall, companies are interested in IT solutions that support effective disruptions, however, not all of them have found suitable ones.

## 5.3 Framework for agility in disruption management

According to the above discussions, the empirical research verifies the practicality of the earlier proposed conceptual framework based on literature. Although most of the identified theoretical points are in line with the practical inputs from case companies, the framework needs some modifications to provide a more comprehensive approach for companies to plan agility in disruption management, particularly during such crisis as the semiconductor shortage. The refined framework is illustrated in figure 10.

The two phases (pre-disruption and post disruption) and four steps (mitigation, detection & preparation, response, recovery & learning) of the disruption management cycle provides a basis for planning proactive or reactive actions to handle supply disruptions. Under each phase, the dimensions of agility (alertness & accessibility, flexibility and speed, decisiveness) are defined and supported by several enablers.

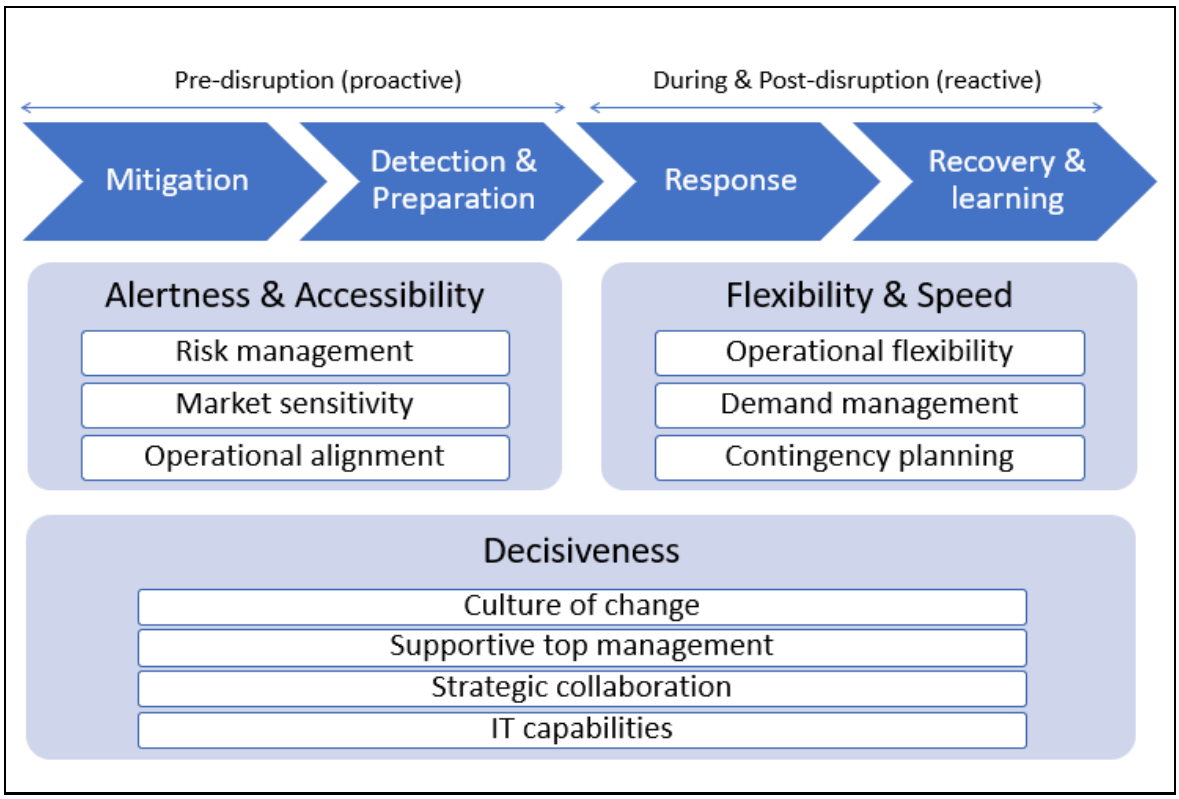


*Figure 10. Modified conceptual framework : Supply chain agility in supply disruption management*

Pre-disruption phase includes proactive activities to mitigate, detect and prepare for the actual disruption events. Thus, agility elements associated in this stage include being alert to new information and ensuring access to the needed resources for risk management planning. Comparing to the earlier framework version, 'strategic sourcing' is considered as a supporter for strategic collaboration and thus is removed, while 'culture of change' is moved to be under 'decisiveness' dimension as it is needed not only before but also after the disruption. According to the findings, the semiconductor shortage was not at all predicted by companies. Thus, having existing supply risk management practicalities (such as buffer stock or alternative suppliers) in place has helped companies in better preparation of reactive approaches in the next phase. As a result, 'risk management' was added to this phase as an enabler for agility. Due to the unpredictability of the semiconductor shortage, being sensitive to the latest market information is crucial in ensuring agility. This is enabled by active information sharing, close collaboration as well as supportive IT capabilities. Also, alignment of supply chain processes was proved to be important in order to have more proactive preparation towards disruption. As learned from the findings, automatizing and streamlining processes have been a target for some case companies, especially those small ones where a complete end-to-end supply chain processes have not been available.

Once a crisis event has occurred and emerged, companies are forced to take reactive actions to response to disruptions and reduce negative impacts. The modification of the framework for this phase is the removal of the enabler 'strategic orientation', which was defined in the literature review as focus on understanding the external environment and willingness to learn (Braunscheidel and Suresh, 2009). Based on the companies' input, strategic orientation was mainly based on the understanding of business partners which contributes to build strategic collaboration needed throughout the crisis management cycle, thus it is removed from the framework. Flexibility is required for agile implementation of supply risk management practices and backup plans defined in the previous phase. Findings from case companies have proved that the feasibility of risk management highly depends on the level of flexibility. However, some companies can be more flexible than others depending on product complexity, dependency on external partners as well as company culture. In addition, demand management should be the focus point during the supply disruption, as there is typically not enough supply to fulfil demand. Supply allocation through customer delivery prioritization, restricting sales as well as flexible partial deliveries are some examples given by case companies when it comes to managing demand during the

crisis. Besides implementing the existing risk management approaches, continuous contingency planning is needed since new disruptions might occur at any time. Planning for recovery should be part of this phase as defined in literature, however the amount of empirical finding is limited as the semiconductor shortage was still at its peak at the time this study was conducted. Finally, continuous learning during and after the crisis should be emphasized as it helps understand the risk areas, refine processes and better prepare for similar crisis in the future.

Throughout the whole disruption management cycle, decisiveness is an element of agility that plays a key role in the realization of reactive and proactive approaches. Decisions need to be made for actions to take place, and quick decision making is considered highly crucial during the semiconductor shortage. The enabler ‘’culture of change’ was added to this part of the framework as it defines decision making practice and flexibility before and after disruptions. Having a culture that fosters continuous changes and improvement as well as empowers employees is a requirement for long-term supply chain agility. Moreover, positive and supportive top management is a part of making the supply chain more agile, as they are open to understanding situations, facilitating changes, making commitment and active investment in improving current practices. As supply chain is the integration of different flows and activities inside and outside the organization, companies should ensure strategic collaboration between internal and external parties to increase flexibility and foster risk sharing. Collaboration in the supply chain is built on close relationships and trust with customers and suppliers, for which strategic orientation or understanding about the partners is utilized. Last but not least, in today’s complex and ever-changing supply chain environment, companies need to increase their IT capabilities to increase end-to-end visibility, align processes and gain access to real-time information needed for rapid decision making. Investments in IT solutions and digital transformation of supply chain has been a focus point for today’s market players to become more agile.

In overall, the framework suggested in this study provides a generic guideline for companies to utilize agility in managing supply disruptions. It was built based on academic literature and empirical findings from multiple case companies during the semiconductor shortage, which contributes both theoretical and managerial values.

# 6 CONCLUSIONS

The purpose of this thesis was to reflect the theories of supply chain agility and supply disruption management through the practical perspective of semiconductor shortage. Application of agility dimensions in managing supply disruptions was studied to understand how having an agile supply chain could help firms to better cope with the semiconductor shortage. The study aimed to answer the following research questions:

*How to utilize supply chain agility in supply disruption management during the semiconductor shortage?*

*(1) What are the impacts of the semiconductor shortage on companies' performance?*

*(2) What is the role of supply chain agility in managing supply disruption?*

The key findings of this research provide answers to the research questions. Firstly, the impacts of supply disruption in general and the disruptions caused by the semiconductor shortage in specific were discovered. Firms are affected both operationally and financially by supply disruptions due to limited supply of components, which can have a direct impact on customer satisfaction and employee well-being. Understanding what kinds of impact caused by the semiconductor shortage helps companies identify suitable mitigation, response and recovery planning and actions. Secondly, most of the approaches to supply risk management suggested in previous literature are practically in place at companies, which have been utilized also when coping with the semiconductor crisis. Thirdly, the implications of agility in disruptions management identified based on literature review seem to reflect the reality in most cases. In overall, supply chain agility plays a key role in successful disruption management during the semiconductor shortage. Elements of agility can be applied in different phases during the disruption management cycle by considering various enablers.

This chapter continues with a further explanation of the main theoretical and managerial contributions of the thesis. Finally, it ends with an elaboration of the study's limitations and suggestions for further research.

## 6.1 Theoretical contributions

In terms of theoretical contribution, firstly, the thesis provides a review of existing literature from the field of supply chain management with a balance between classic works and new studies. In addition, the literature review of this study provides an addition to the limited amount of research on the semiconductor shortage. The conceptual framework developed in this study creates a link between the theory of supply disruption management and supply chain agility. It synthetizes the elements and enablers of agility in supply disruption management processes. As a result, this framework of this study fills in the two gaps identified from Calvo et al. (2020)'s framework, which are: (1) Agility is included only in the post-disruption phase and (2) Lacking dimensions and enablers of agility. The research findings confirmed the practical business application of the theories in the event of the semiconductor shortage crisis. Furthermore, thanks to the variety in case company's background, the finding identified additional aspects that were not specified in literature, such as the dependency of agile implementations on product complexity, supply chain characteristics and external partners.

## 6.2 Managerial implications

When it comes to implications for management, the modified framework (presented in chapter 5.3) based on literature review and empirical findings provides managers with guidelines on how to utilize agility in supply disruption management. The model can be applied not only in the context of the recent semiconductor shortage but also in similar crises.

In addition, the study suggests the best practices for managers in coping with the semiconductor/component shortage. As learned from the case companies, having existing risk management practices such as buffer stock, alternative suppliers, alternative components, and flexible product redesign were essential in preparing and reacting to supply disruptions. Enhancing alertness and accessibility to information requires alignment of supply chain processes and close collaboration with internal functions and external partners. Flexibility and speed are important factors in responding to disruptions, which can be enhanced by maintaining a culture of change that fosters continuous improvement and proactive decision making. Investments in IT capabilities, including tools and know-how, should be a focus to automatize processes, manage flows and gain access to real-time information. The ERP system is a backbone of supply chain operations in many

organizations, which can be supported by other function-specific solutions such as partner interface, demand planning, procurement and product data management. Besides the improvement of technological capabilities, human management factors should not be neglected. As identified in the findings, the amount of workload during the semiconductor shortage significantly increased for many supply chain functions, thus, managers should pay attention to amount of employees' workload during disruption events and take care of their wellbeing and motivation. When it comes to employee empowerment, managers should find the right balance between flexibility and authority: giving people the freedom to make decisions but at the same time have a clear definition of what can be decided.

Since supply chains vary from one organization to another, there is no one-size-fits-all approach for firms to follow. Nevertheless, this thesis provides ideas and suggestions for companies across different industries to determine the most suitable approaches for their organization to achieve supply chain agility and utilize it in disruption management.

## 6.3 Limitations and recommendations for further research

The limitations of this thesis are presented in parallel with the recommendations for further research. Firstly, as the thesis was conducted between January and May 2022 when the semiconductor crisis was still on going, there were limited findings on approaches taken for recovery and learning from the disruption. As a result, further research at a later point will provide a more complete view on the whole management cycle of the semiconductor shortage crisis.

Secondly, the case companies who agreed to participated in the research operates mainly in Finland and in the manufacturing industry. Also, interviews were conducted with only one or two employees representing a specific function for an organization. Thus, further research with companies from other countries and industries would likely provide more varied perspectives to the research. Moreover, the involvement of company representatives from multiple supply chain departments could bring interesting angles to the topic from the same organization.

Thirdly, the focus of this thesis is mainly on organizations who act as supplier tier 1, which locate closer to the downstream of the supply chain and whose final products and operations rely on components needing semiconductors. Thus, it would be interesting to

study the topic from the perspective of upstream supply tiers - semiconductor manufacturers, chip designers or distributors.

Furthermore, neither the costs of adopting agility practices in the supply chain nor the impacts of agility on a company's financial performance were in the scope of this study. In today's competitive environment, cost impacts and profitability are the main concerns of most companies. Therefore, another suggestion for further research would be to investigate the financial implications of supply chain agility in disruption management.

Finally, as this study covers multiple dimensions of agility on a relatively high level, there is much room for future research focusing on a single aspect for achieving agility, for instance culture or technology, in managing disruptive crises.

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# Appendix: Interview questions

BACKGROUND

1. Could you briefly introduce the company and your role in the organization?
2. How would you describe the company's supply chain?
3. How would you describe the role of semiconductor/chips in the company product portfolio?
4. How has the semiconductor shortage affected the company's operations?

SUPPLY DISRUPTION MANAGEMENT

**Mitigation and preparation**

5. What kind of supply risk management approaches there are in the company? How have they helped during the component shortage?
6. How information about market changes is usually identified?
7. What is the role of suppliers during supply disruptions?
8. How would you describe the company culture and its impacts on supply disruption management?
9. What are the approaches the company has used to align different supply chain processes and systems? How has such alignment helped during the shortage?

**Responsiveness**

10. What kind of actions the company has taken in response to the component shortage?
    - What could have been done better?
11. Has there been any backup plans to deal with the shortage? How have they been implemented?
12. How would you describe the flexibility of the company supply chain in terms of sourcing, manufacturing, and logistics?
    - What are the main obstacles for the company to be more flexible?
13. How the customers had reacted towards the impacts of the shortage? How did the company response to those?

**Decisions making:**

14. How has the management supported during the crisis?

- Has decision making been sufficient in terms of speed and effectiveness?

**Strategic collaboration:**

15. How much involved are other supply chain parties (supplier, customer, 3rd party provider) in communications and planning of supply chain activities?

**Information technology**

16. What kind of IT capabilities has been used to help dealing with the shortage?
17. Is there any new IT/analytics tools or resources that the company is planning to adopt to better deal with similar crisis?

**Recovery & Learning**

18. How is the situation with the shortage up to now? Has the company been able to recover somehow?
19. What are the most important lessons learned from the crisis?

CONCLUSION

20. How successful do you think that the company has been in mitigating and responding to the shortage? Why?
21. Is there anything else that you would like to add?