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School of Business and Management

Supply Management

MASTER'S THESIS

BUSINESS IMPACT ANALYSIS OF SUPPLY CHAIN DISRUPTIONS

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ABSTRACT

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The purpose of this Master's thesis is to find out how to estimate the business impact of supply chain disruptions. The role of supply risk management is becoming more and more important. Even though there exist large amount researches relating to supply risk management, only few focuses on the business impact of supply chain disruptions.

This research study utilizes both qualitative and quantitative research methods. The qualitative data is collected from semi-structured interviews whereas quantitative data is collected from the database of the case company. The interviews are used as a background for analyzing quantitative data which aims to develop a new business impact calculation model. The findings introduce that suppliers have a crucial role especially in manufacturing companies and for this reason it is important to recognize the risk related to suppliers. Identifying most critical suppliers makes it possible to develop supplier relationship management and comparing different scenarios. This in turn, enables improving proactive supplier base management.

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Tämän pro gradu -tutkimuksen tarkoituksena on selvittää, kuinka toimitusketjun häiriöiden aiheuttamaa liikevoiton menetystä voidaan arvioida. Riskien hallinnan rooli hankintojen johtamisessa on kasvanut viimeisen vuosikymmenen kuluessa selvästi. Tästä huolimatta aiemmassa kirjallisuudessa ei ole keskitytty juurikaan toimitusketjun häiriöiden aiheuttamiin taloudellisiin vaikutuksiin. Päätavoitteena on kehittää business impact laskentamalli case-yrityksen tarpeisiin.

Tässä tutkimuksessa käytetään sekä laadullista että määrällisiä tutkimusmenetelmiä. Laadullinen aineisto kerätään puolistrukturoitujen haastatteluiden avulla ja määrällinen aineisto koostuu case yritykseltä kerätystä datasta. Haastatteluilla toimivat pohjana datan analysoinnille, jonka tavoite on kehittää uusi laskentamalli. Tulokset osoittavat, että toimittajilla on merkittävä rooli erityisesti teollisuusyrityksissä ja tästä syystä toimittajiin liittyvien riskien tunteminen on tärkeää. Kriittisimpien toimittajien tunnistaminen tarjoaa mahdollisuuksia kehittää toimittajasuhteiden hallintaa sekä vertailla erilaisia skenaarioita, jolloin voidaan lisätä proaktiivisuutta toimittajakentän hallinnassa.

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Finally I want to thank my family for all their support during my studies. Special thanks go to my fellow students. You have made my years at LUT unforgettable. As I finish my studies and move into working life, I feel grateful for the education, lifelong friends and all the experiences I have got in Lappeenranta.

In Espoo 23.5.2019

Antti Sahi

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1. Introduction

Fire at a Phillips semiconductor plant in 2000, caused loss of $400 million for Ericsson (Chopra and Sodhi 2004; Gao 2015). According to Pettit, Croxton & Fiksel (2013) Toyota's production drop by 40 000 vehicles, causing $72 million loss of profit per day in 2011 because of the earthquake, tsunami and the subsequent nuclear crisis in Japan. The catastrophic Thailand flooding in October 2011 disrupted the supply chains of computer manufacturers and Japanese automotive manufacturers which have plants in Thailand (Chopra & Sodhi 2014). These are just few examples of supply chain disruptions from recent decades, but they indicate the significance of this phenomenon. This research focuses on analyzing how supply chain disruptions may impact on the financial performance by developing a calculation model from the perspective of global manufacturing company. The purpose is to understand how supply chain disruption caused by single suppliers are affecting to the profit of the case company.

This introduction chapter consists of the background of the study, introduction to previous studies for identifying research gaps, definition of research problems and objectives of this study as well as theoretical framework and limitations. In addition, it presents the definitions of the key concepts and outline of the paper.

1.1 Background of the study and research gaps

This subchapter presents a short overview of the earlier literature about the main topics of this research. The purpose of this chapter is to recognize the research gap for this research by analyzing characteristics of existing literature.

Every purchasing organization faces supply risks and they must decide how to deal with those (Zsidisin 2003). Vulnerability of supply chains has increased during recent decades due to globalization of supply chains, increased outsourcing, reduced buffers, capacity limitation of key components and reduction of supplier

base. This has emphasized the importance of supply chain risk management. (Norrman & Jansson 2004) Thus, companies should focus on risks of their suppliers in addition of focusing on their own risks (Souter 2000).

Supply risks can be divided into individual supplier failures and market factors. If risks realize, in the most severe case, it may result in inability of buying company to fulfil customers' demands. (Zsidisin 2003) As Kraljic (1983) states, ensuring uninterrupted flows of direct materials has been one of the main objectives of supply management and it can be seen that this objective is still valid. However, this increased complexity of supply chains has caused that companies will face more risks of supply chain disruptions. Thus, it can be said that complexity is one of the main challenges for supply chain management as it is a key source of supply chain disruptions. However, despite their complexity, most manufacturing supply chains have similar structure as typical manufacturing supply chain consists of suppliers, their suppliers, assembly plants, distributors, retailers, inbound and outbound logistics providers and financial institutions (Gaonkar & Viswanadham 2004).

Over the past decade, many researchers have examined supply chain risk management by focusing on the areas of defining, operationalizing and mitigating risks (Ho et al. 2015). Majority of earlier literature relating to supply risk management concentrates on presenting supply risk management strategies (Hallikas et al. 2004; Hoffman et al. 2013; Manuj & Mentzer 2008a). Supply risks have been started to study more during recent decades. Sheffi & Rice (2005) and Thun & Hoenig (2011) have examined supply chain risk management in the automotive industry. They point out that companies realize the potential threat of supply disruptions. Many companies have begun to closely follow the status of their suppliers by focusing for example on their production progression, quality performance and financial health (Gaukler, et al 2008; Choi et al. 2008; Babitch 2010). However, multiple researches (Blackhurst et al. 2005; Jüttner 2005; Mitroff & Alpaslan 2003; Thun & Hoenig 2011) point out that even though supply disruptions are considered increasingly as one of the main concerns by risk managers, companies are often unprepared for disruption incidents.

Also, literature relating to supply chain disruptions focuses on mitigation approaches and techniques (Tang 2006b; Zsidisin et al. 2004) In addition, it is typical to examine risks on generic level and determine only the impact on the supply chain (Wu, Blackhurst & O'grady 2007). However, even though the awareness of supply chain disruptions has increased, the concept of supply chain disruptions is still in an early stage since the focus is mainly on a production plant as a single unit as Jüttner et al. (2003) point out.

Both the quantity and severity of man-made and natural disruptions have increased during the past decades and it is assumed that this progress will continue (Allianz 2015; Stecke & Kumar 2006; Tang 2006b). In addition, supply disruptions have become costlier whereas natural disasters are occurring more often, and their financial impact is usually greater than before. Costs of supply risk incidents have increased especially on high tech, industrial products and diversified manufacturing industries that may be explained with their complex, interwoven and time-sensitive nature of supply chains. (Marchese & Paramasivam 2013) This emphasizes the importance of this research as the case company operates on manufacturing industry. Norrman & Jansson (2004) illustrates that the financial impact of supply disruptions can be significant as a fire at Ericsson's sub-supplier points out. However, the financial impacts of supply disruptions receive only little attention in earlier literature. Hendricks & Singhal (2003) examine disruption costs from the perspective of shareholders. Whereas Wu et al. (2007) have designed a Disruption Analysis Network model for analyzing how disruptions expand within supply chains and calculating their impacts.

One reason for increased number of researches relating to supply disruptions may be current business trends such as global sourcing, outsourcing, reduction of supply base, utilization of just-in-time inventory system and shorter product life cycle (Bello & Bovell 2012; Brandon-Jones et al. 2014; Craighead et al. 2007; Hendricks & Singhal 2005; Norrman & Jansson 2004; Sheffi & Rice 2005; Wagner & Bode 2006). Tang (2006b) points out that these trends are popular because they are increasing revenue and reducing costs. In addition of these benefits, they are making supply

chains more complex and vulnerable for different disruption events (Bello & Bovell 2012; Brandon-Jones et al. 2014; Wagner & Bode 2006).

In existing literature, it is prominent that researches focus typically on only single supply disruption type at a time. Furthermore, Colicchia, Dallari & Melacini (2011) notifies that only few earlier researches have applied theoretical approaches for managing supply chain risks in real-life contexts. Hence, this research takes more universal perspective and focuses on examining most common and critical supply chain disruptions from the perspective of the case company. Figure 1 presents central notifications from prior literature and research gap identified for this research.

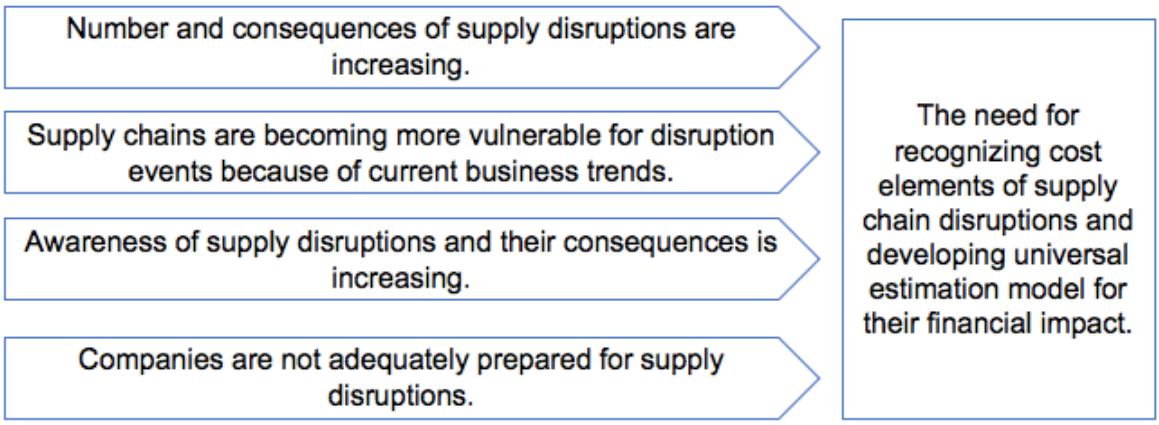

Figure 1 Central notifications if supply risk management literature and research gap

This research is done for a manufacturing company that operates on global markets and is one of largest companies in its industry. The role of supply risk management has been emphasized in the company during recent years and there have made remarkable development activities. The company has focused on recognizing potential disruption events and there exists business continuity plan for each supplier that will be updated regularly. However, there is a need for information about business impact of suppliers' delivery disruptions.

The company estimates possible costs and probability of suppliers' supply risks as well as internal risks but at this moment, potential business impact of supply risks is not assessed. Objective of this research is to develop refined model for calculating

business impact caused by supply chain disruptions. This information would offer a possibility to focus on most critical suppliers and be a tool for supplier risk and relationship management.

1.2 Research questions and objectives

This research has two main objectives. First one is investigating how supply chain disruptions are causing profit loss of case company whereas second one focuses on how business impact of disruptions could be calculated. The background of the research is case company's need to identify what are the financial impacts of supply chain disruptions and what are most critical suppliers. Case company has started to focus more on supply risk management during recent years and the purpose of this thesis is to create a calculation model for simulating loss of profit caused by suppliers. This objective justifies the need for this research and sets starting point for defining research questions.

Based on objectives set out for this research, there can be defined two main research questions and two sub-questions which are formulated as table 1 below.

Table 1 Research questions

Research Question	Objective
RQ 1. What are the costs that upstream supply chain disruptions are causing in manufacturing industry?	To identify what kind of additional costs supply chain disruptions are causing.
RQ 1.1. What disruption events are seen most critical?	To identify the event types that are considered most critical.
RQ 1.2. How disruptions costs can be mitigated?	To identify how disruptions costs can be reduced and mitigated.
RQ 2. How to calculate business impact of upstream supply chain disruptions?	To identify requirements to business impact calculation model. To identify how to estimate business impact with calculation model.

Research question 1 studies costs of upstream supply chain disruptions. The objective is to identify what kind of additional costs supply chain disruptions are causing. For answering to this question, it is important to identify what kind of disruption events are most common or several that is the objective of sub-question 1.1. In addition, responsibilities of supply chain members and mitigation activities set up by the case company are affecting to the final financial impacts that is examined with sub-question 1.2.

Research question 2 focuses on analyzing financial impacts of supply chain disruptions. The objective is to develop a calculation model which estimates how supply chain disruptions are affecting to the case company's profit loss. The requirements for this model are defined with interviewees from the case company.

1.3 Theoretical framework and limitations

The theoretical framework of this thesis, presented in figure 2, focuses on supply risk management, supply chain disruptions and business impact analysis that are three main theoretical areas in this thesis. These three areas are closely related inside the supply risk management frame.

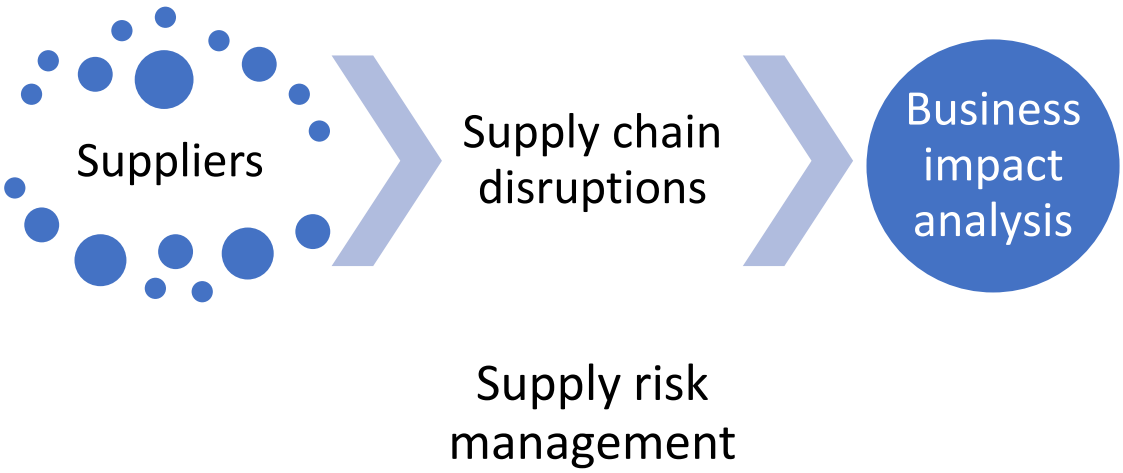

Figure 2 Theoretical framework of the thesis

The figure illustrates how suppliers' face disruptive events which may have business impacts also on the buying company. Thus, the scope of this thesis covers only upstream supply chain disruptions which have impacts on buying company's operations.

There are limitations related to this research that need to be considered. Johnson (2001) divides supply chain risks between supply risks and demand risks. Supply risks consist of for example capacity limitations, currency fluctuations and supply disruptions whereas demand risks focus on seasonal imbalances, volatility of fads and new products. Similarly, Tang (2006a) classifies supply chain risks into operational and disruptions risks. Operational risks cover uncertain customer demand, supply and costs whereas disruption risks are related to natural or man-made events. It is typical that disruption risks have greater business impact than operational risks. In this research, the focus is only on supplier related supply chain disruptions including also operational risks related to suppliers, but demand risks are left out of the scope. This limitation leaves away disruptions caused by customers' actions and the functions of the case company. It is assumed that disruptions will cause complete production stops for suppliers and due to this they are not able to deliver any materials until the recovery actions are executed. This research focuses on one case company and thus it represents a single phenomenon. As the case company is large multinational company, this sets limitations for utilizing the results of this research in small and medium sized companies because the structure of supply chain, the size of supply base and the level of risk management may vary greatly across companies. In addition, as Stuart et al. (2002) states opportunities for generalization of the findings are limited because the research is conducted as a single case study.

The theoretical part of this research is limited to cover the background of supply risk management, concepts of business impact analysis and business continuity planning as well as closer analysis of supply chain disruptions. Supply risk management is presented through steps of risk management process, main supply risk types and vulnerability and resilience of supply chains. This limitation is made for underlying second theory chapter which goes deeper into different disruption

events. Examining supply chain is limited to cover only upstream dimension because the focus of this research is on supply disruptions caused by suppliers. Supply disruptions are classified into three main categories based on earlier literature. In the empirical part, supply disruptions are analyzed from the perspective of the case company. The industry of case company limits this research to the manufacturing industry and topic is examined from the perspective of buying company. These limitations are made for keeping the scope of this research compact and focus is on finding answers to the research questions.

1.4 Definitions

This section presents briefly definition for the main concepts that the reader needs to consider. They will be defined more accurately in the theoretical part of this research.

Supply risk management (SRM)

Identifying risks related to supply chain and setting up mitigation actions for those (Harland et al. 2003). Supply risk management can be divided into three phases which are 1) risk identification, risk measurement and risk assessment, 2) risk evaluation and risk mitigation & contingency plans and 3) risk control and monitoring (Tummala and Schoenherr 2011).

Supply Chain

The supply chain comprises all activities related to the flow and transformation of goods from raw materials stage, through to the end user, as well as the associated information flows (Handfield & Nichols 1999).

Supply disruption

Supply disruptions are radical transformations in the structure of the supply chain through the non-availability of certain production, warehousing and distribution facilities or transportation due to unexpected event that is caused by human or nature. (Gaonkar & Viswanadham 2004)

Business continuity planning (BCP)

A system which primary objective is to minimize the effects of unanticipated events on the company's ability to fulfil customer requirements (Zsidisin, Melnyk & Ragatz 2005).

Business impact analysis (BIA)

BIA sets the basis for business organizations to plan their recovery strategies. It can be used to identifying and prioritizing mission-critical functions. The effectiveness of BIA is related to the management's commitment of people and technological resources to mitigate risks. (Sikdar 2011)

1.5 Structure of the study

This research consists of seven chapters which are presented in figure 3. Introduction chapter presents overview and background of the thesis. Following two chapters focus on main theories of this research. Chapter two introduces the concept of supply risk management which is the main theme of this thesis. This chapter presents also the theory of business continuity planning focusing especially on business impact. Third chapter goes deeper into supply chain disruptions by presenting main disruptions types and impacts of disruptions. The purpose of theoretical part is to gain deep understanding of supply risk management and supply disruptions based on existing literature.

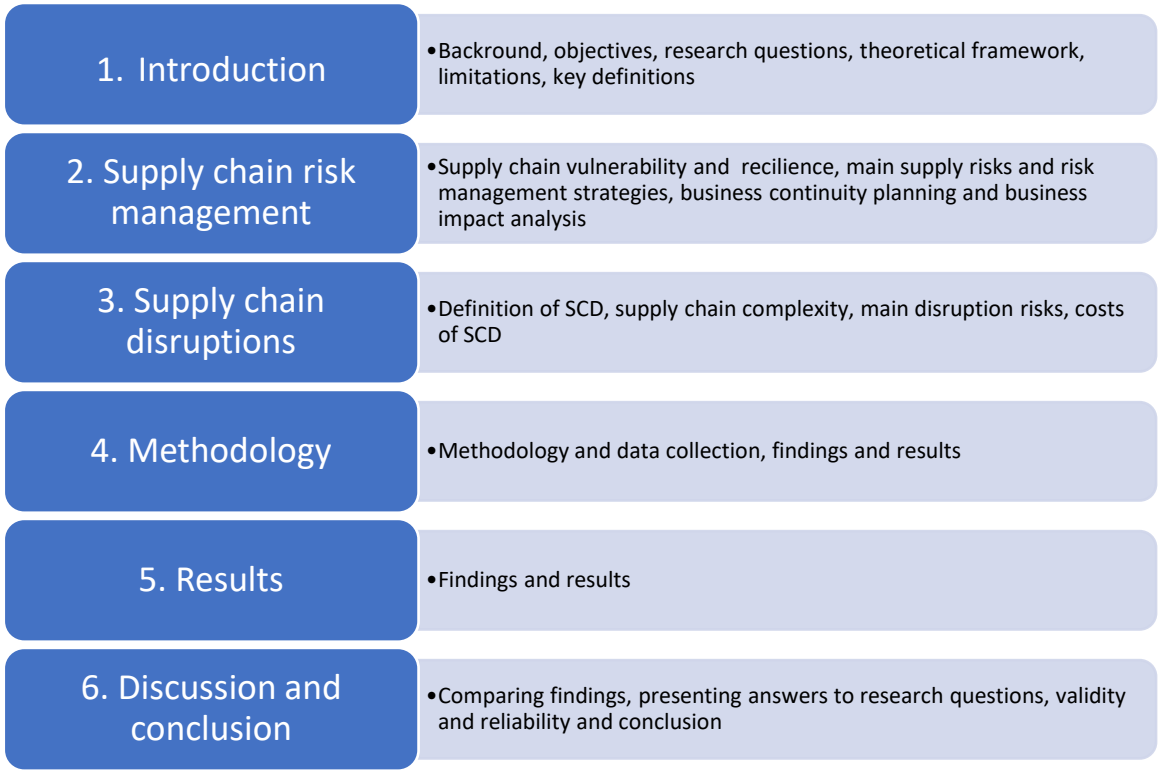

Figure 3 Structure of the thesis

Chapter four begins with presenting and explaining the research methodology which is used in this research. The empirical part consists of two parts. The first part of empirical study bases on the interviews in the case company. This part examines the current state of supply risk management, potential costs of supply disruptions and what would be requirements for the calculation model. The second part in turn, utilizes quantitative data from the database of the case company. This part aims to developing a calculation model which makes it possible to analyze business impact of potential supply disruptions on supplier level. Fifth chapter combines these two parts for presenting results. Last chapter consist of discussion of results, suggestions for future studies and concludes main findings of the thesis.

2. Supply chain risk management

The aim of this chapter is to examine the characteristics of supply chain risk management as well as present main supply risks and risk management strategies. Following sub-chapters will go through central topics of supply chain risk management and finally introduce concepts of business continuity planning and business impact analysis.

2.1 Managing supply chain risks

According to Zsidisin (2003), supply chain risks mean the probability of an incident occurring failures of individual supplier or the supply market that cause the inability of the purchasing company to meet customers' demands or even threat customers' life and safety. Colicchia & Strazzi (2012) define risk in terms of likelihood of occurrence and its impact. Supply chains have become increasingly complex and dynamic during recent decades because of increasing product/service complexity, outsourcing and globalization and according to Harland et al. (2003) this has a straight impact on supply chain risks. Gaonkar & Viswanadham (2004) state that risks have always been present in supply chains and last decade's development has increased the risk level as supply chains focus more on efficiency instead of effectiveness, supply chains have become more global, factories are more focused and distribution centralized, increased outsourcing and reducing the supplier base and volatility of demand. This makes it extremely important that focal companies of supply chains utilize risk management tools for managing their supply chains. Fang et al. (2013) add that globalization of supply chains has made supply of all types of materials vulnerable for disruptions. For this reason, it can be said that performing supply chain risk management may lead to a significant competitive advantage (Kirilmaz & Erol 2017). According to Norrman & Jansson (2004) insurance companies might be driving force for the improvement of supply chain risk management as they start to understand better the vulnerability of modern supply chains.

The chance of business environment has increased the meaning of risk management since, as Harland et al. (2003) state, managing the consequences of risk may be very difficult. Kern et al. (2012) point out that popular initiatives in supply management, such as outsourcing, reduction of inventories, just-in-time concepts and increasing inter-firm cooperation have made supply chains leaner but at the same time more fragile. Kirilmaz & Erol (2017) presents an example that as globalization and use of e-trade decrease raw material or product costs, especially when procuring from the Far East, supply chains will become longer, and intercontinental transportation is vulnerable for multiple risks. These risks base on communication, geopolitical, cultural, transportation or legal complexities. If one or more of these risks realize, consequences to the purchasing company will be significantly higher than advantages of low-cost country sourcing.

Tang (2006a) argues that supply chain management deals mainly with five interrelated issues which are 1) supply network design, 2) supplier relationship, 3) supplier selection process (criteria and supplier selection), 4) supplier order allocation and 5) supply contract. When switching to use back-up suppliers in case of major disruption, companies must develop a model for analyzing suppliers' dynamic supply configurations, including contract manufacturers and logistics service providers, for capturing the dynamics of shifting. According to Harland et al. (2003) the key drivers for increased complexity in supply networks are product/service complexity, e-business, outsourcing and globalization. Complicated products and services cause for example problems with scale, quantity of sub-system components, skills and competences of personnel and extent of supplier involvement. This has connection with outsourcing as single companies are not capable of doing all by themselves. Increased outsourcing leads to access to global markets and globalization of supply networks as companies search international sources for materials and services. E-business is also in connection with globalization as it provides an access to the market. Hence, both complexity of supply networks and supply risks increase. For reducing these risks Vedel & Ellegaard (2013) state that gathering risk related information and its generation are central tasks for the supply chain manager. They argue also that managing supply risks includes reducing probabilities and effects of events which cause losses in the

upstream supply chain. Harland et al. (2003) notes that there can be seen a connection between supply chain complexity and supply risks as the more complex supply chain is the greater supply risks are.

There exist multiple different types of supply chain risk management functions in the literature (Vedel & Ellegaard 2013). First views of supply chain risk management were seen in Kraljic's model in 1983 where risk is one dimension of the model. During following decades, supply risks have studied broadly, and the main purpose of researches has been investigating strategies to reduce risks in supply chains. (Harland et al. 2003) Manuj & Mentzer (2008a) in turn, points out that there are lack of conceptual frameworks and empirical findings that provide exact meaning and normative guidance on the global supply chain management. They state that companies must first recognize risks and then choose strategies how to deal with them. This path consists of 5 steps which are shown in figure 4.

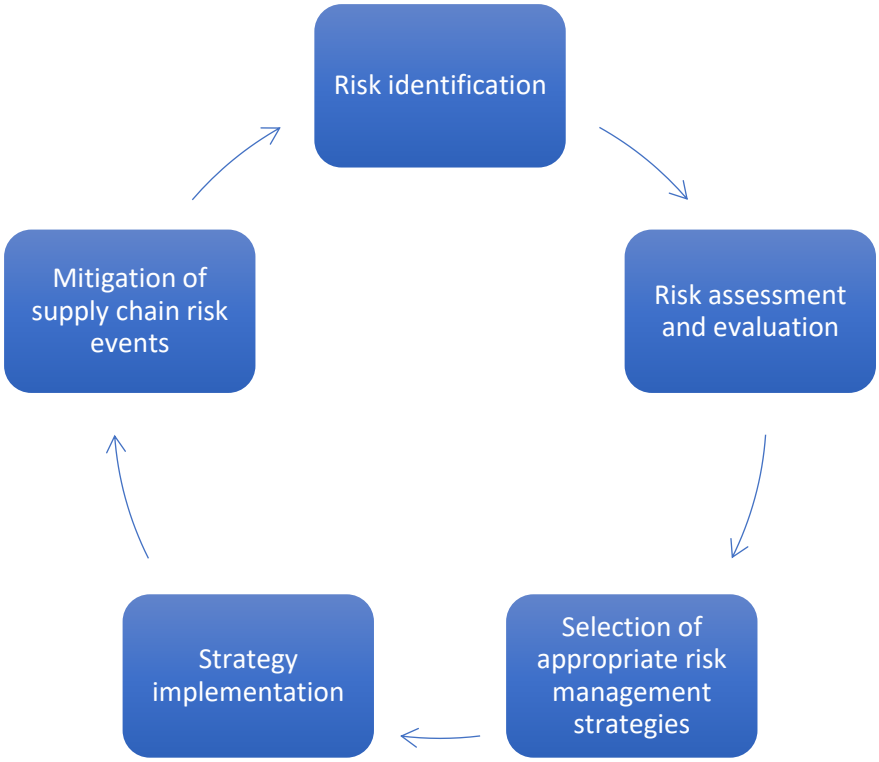

Figure 4 Risk management process (based on Manuj and Mentzer 2008a, 137)

Also, Kern et al. (2012) present a model for risk management with 5 steps. These steps are 1) risk identification, 2) risk assessment, 3) risk mitigation, 4) risk performance and 5) continuous improvement process which in connection with first three steps. In their research, they investigate how risk identification effects on risk assessment which has further an impact on risk mitigation. Risk mitigation in turn is connected with risk performance as only risk mitigation activities can decrease the impact of risk incidents. Tummala & Schoenherr (2011) introduces their supply chain risk management process which composes six steps which are divided into three phases. Phase 1 includes risk identification, risk measurement and risk assessment. Risk evaluation and risk mitigation & contingency plans comprise phase 2 and phase 3 includes risk control & monitoring. In addition of these three phases, their process model includes both internal and external drivers relating on sourcing and market environment, risk categories and supplier/logistics evaluation criteria and performance measures.

In addition, typical risk management process model presented by Hallikas et al. (2004) includes partly same steps. Their model consists of four steps which are 1) risk identification, 2) risk assessment, 3) decision and implementation of risk management action and 4) risk monitoring. There can be seen lot of similarity between these process models as almost all of them include same main steps: risk identification, assessment, strategy implementation and risk mitigation. However, Hoffmann et al. (2013) state that supply risk mitigation and especially supply chain risk management maturity have strongest influence on supply chain risk management performance and decreasing negative effects of environmental uncertainty. They emphasize the meaning of implementing supply chain risk management process as it is more important than selection of individual risk monitoring and mitigation strategies.

2.2 Supply chain vulnerability

Christopher & Lee (2004) argue that supply chain vulnerability has increased during recent years regardless of industry. Wagner & Bode (2006) state that the reason for

this is a combination of several trends and factors such as increased competition and globalization that has resulted in a significant pressure to develop interfirm and intrafirm business processes more efficient such as offshoring manufacturing, sourcing in low-cost countries and reducing stock. However, these initiatives increase often interfirm dependences as well as the vulnerability of supply chains (Christopher & Peck 2004). Supply chain vulnerability evaluates supply chain's capacity to predict, cope with, resist and recover from disruptive events. These are related to the supply chain's density, complexity and criticality of facility. (Craighead et al. 2007) According to Wagner & Bode (2006) supply chain vulnerability can be seen as the susceptibility or exposure to a disruption in the supply chain. Managing supply chain vulnerabilities requires that companies know how much vulnerability exist in their supply chain and what are drivers of vulnerability, so that they achieve an acceptable level of supply chain vulnerability based on desired risk-reward trade-off (Wagner & Neshat 2012).

Blackhurst et al. (2018) point out that better capability to measure and manage supply chain vulnerability could reduce the quantity of disruptions and their impact. They state that negative impacts from supply chain disruptions can be seen as manifestation of the supply chain vulnerability. However, measuring supply chain vulnerability is complicated since it consists of so-called drivers of vulnerability such as globalization of the sourcing network, customer or supplier dependence and supply chain complexity. Hence, supply chain vulnerability cannot be measured directly. Instead, these drivers must be measured and their interrelations and combine them for the supply chain vulnerability construct. (Wagner & Neshat 2012)

According to Sheffi & Rice (2005) vulnerability assessment bases on three questions: "What can go wrong?", "What is the likelihood of that happening?" and "What are the consequences if it does happen?". Because contributing factors are varied and detailed and there are not effective tools for measuring them, there cannot be presented a single expected vulnerability metric. Instead, it is possible to categorize potential disruptions based on their probability and consequences. There can be seen that the vulnerability to a specific disruption varies significantly between companies. For example, a terrorist attack has high probability for both American

Airlines and McDonald's, but the impact is high only for the first one as disabling one or few franchise restaurants locally does not put pressure on the bottom line of a company that has over 30 000 restaurants. On the other hand, clothing retailer Limited Brands has low probability of terrorist attack, but as it processes major part of its merchandise through a single distribution center, an attack against the distribution center would cause several impacts also for Limited Brands. Whereas Ace Hardware have both low probability and impact of terrorist attack since it has low profile and thus company is not an obvious target. In addition, Ace Hardware has thousands of retail outlets and dozens of distribution centers that make it easier to sustain a single-point disruption.

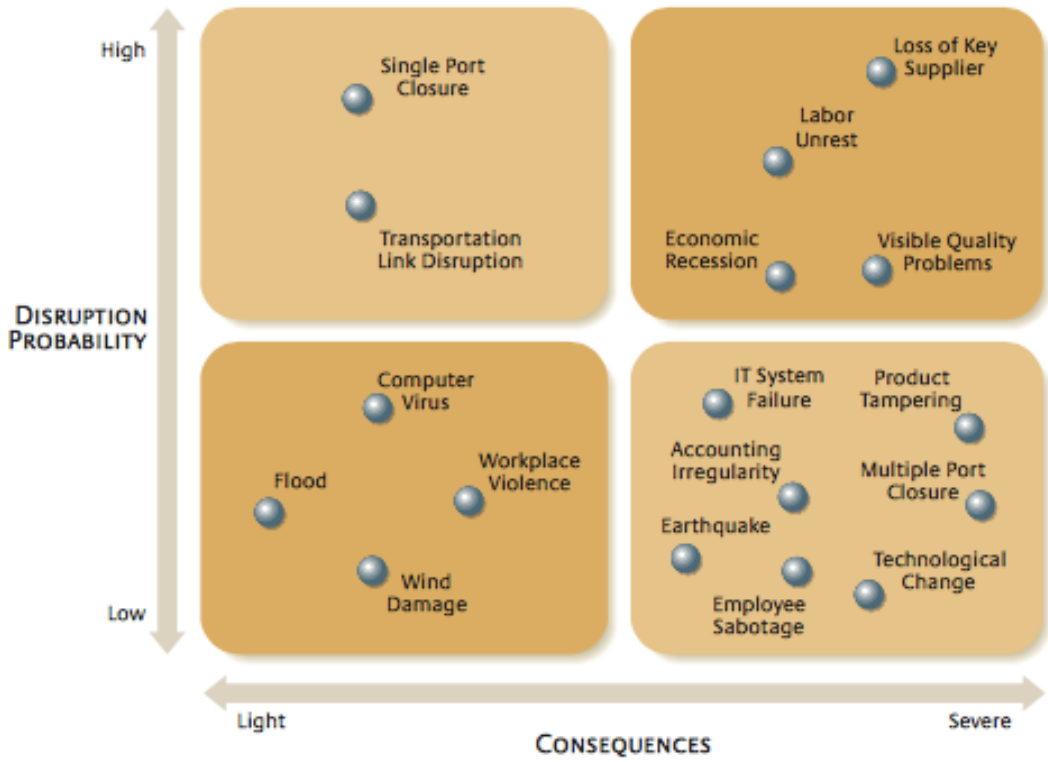

Figure 5 A Vulnerability Map (Sheffi & Rice 2005)

Companies may create a vulnerability map for directing management attention to most important risks and prioritizing planning by placing various disruptive events in the appropriate quadrant of the vulnerability framework. An example of the map is presented in the figure 5. Vulnerability maps require continuous updating since new disruptive events emerge as well as the probability and impact of disruptions may

chance with a company's actions. In addition of familiar disruptions such as financial problems of suppliers and natural disasters, supply chain management must pay attention to the vulnerabilities of more complex, sensitive supply chains. (Sheffi & Rice 2005) According to Blackhurst et al. (2018) visualizing the supply chain and analyzing vulnerability areas help companies to identify vulnerable locations before a disruption realizes. Furthermore, it is extremely important to understand how factors such as connectivity and design of the supply chain are impacting to the supply chain vulnerability (Wagner & Bode 2006). Chopra & Sodhi (2004) point out that design of the supply chain may have an impact on the level of its vulnerability since there exists trade-offs between different risk types. Managers must be aware of the fact that actions to reduce one risk may increase the likelihood or impact of another risk. Bode & Wagner (2015) point out that using multiple suppliers reduces supply chain vulnerability through enhanced flexibility and resilience even though it increases the complexity of supply chain.

2.3 Supply chain resilience

Christopher & Peck (2004) define supply chain resilience as company's ability to return to its original state or move to better state after being disturbed. Supply chain resilience can be seen as supply chain's adaptive capability to prepare for unexpected events, react to disruptions and recover from them (Ponomarov & Holcomb 2009). The importance of supply chain resilience has become significant because of increased amount of supply chain disruptions (Chowdhury & Quaddus 2017). Spiegler et al. (2012) notifies that supply chain resilience requires that companies achieve three attributes. Firstly, supply chain must have readiness to provide goods or services at reasonable costs. Second one is a quick response to which means minimizing the reaction time against disruptions and beginning the recovery phase whereas third attribute is recovery to the normal state. Chowdhury & Quaddus (2017) point out that supply chains should develop both proactive and reactive capabilities for raising the level of readiness, response and recovery ability in case of the pre-disaster and the post-disaster situations. Every company is depending on the web of suppliers, logistics companies, brokers, port operators,

dealers and many other parties that make possible its business processes and the resilience bases on company's competitive position and the responsiveness of the whole supply chain (Sheffi & Rice 2005).

Supply chains need proactive resilience capabilities to react against disruptions (Jüttner & Maklan 2011). There exist multiple proactive capabilities such as flexibility, redundancy, robustness, collaboration and financial strength (Pettit et al. 2013). Reactive perspective towards supply chain resilience bases on company's response and recovery abilities (Sheffi & Rice 2005). Pettit et al. (2013) states that the aim of supply chain response is to minimize the impact and reacting time for disruption. According to Jüttner & Maklan (2011), ability to respond quickly on disruptions may be unique source of competitive advantage for resilient companies. Recovery from disruptions in turn, is a critical capability for companies and their supply chains (Chowdhury & Quaddus 2017). Supply chain resilience is typically measured based on recovery time. However, it is important to consider recovery cost as well (Vugrin et al. 2011). Chowdhury & Quaddus (2017) identify that resilience can be measured based on recovery time, cost, disruption absorption and ability to reduce the impact.

Earlier literature recognizes multiple strategies for building resilient supply chains, i.e. redundancy, flexibility (Sheffi & Rice 2005), supply chain re-engineering and supply chain collaboration (Christopher & Peck 2004). Redundancy can be defined as keeping some resources in reserve in case of a disruption. Safety stocks, use of multiple suppliers and low capacity utilization rates are the best-known forms of redundancy. Flexibility instead, can be seen to be more efficient method to develop resilience of supply chain. Flexibility is related to organic capabilities that can notice threats and respond to them quickly. In addition, this creates competitive advantage in the marketplace. (Sheffi & Rice 2005) Supply chains have been traditionally designed to optimize for cost and customer service. However, resilience is rarely among the objective functions for the optimization process. Recent development such as globalization of supply chains has changed the situation and design of supply chain should be made risk reduction in mind. Supply re-engineering implies that resilience should be designed into a supply chain. As supply chains extend

typically across different organizations, supply chain collaboration can significantly help mitigating risks and the main challenge for companies is to create conditions where collaborative working is possible. Collaborative working demands that potential risks are identified and managed. (Christopher & Peck 2004)

There exist also trade-offs between supply chain resilience and costs since it is costly to sustain flexibility and redundancy through risk mitigation activities such as safety stocks, additional suppliers and backup sites (Spiegler et al. 2012). Nevertheless, Christopher & Peck (2004) point out that also lack of resilience may cause costs as a result of poor customer service level, vulnerability and possible loss of control. Spiegler et al. (2012) states that organizations must make thoughtful decisions based on their strategic objectives and for this reason it is important to take into account trade-off between supply chain resilience and costs. Chowdhury & Quaddus (2017) state that developing resilience requires that companies have supply chain disruption orientation, a resource configuration and a risk management infrastructure implemented.

2.4 Main supply risks

As described in the chapter 2.1, it is important to identify potential supply risks for managing them properly. Globalization has opened new markets for companies and relieved making new product/service innovations. At the same time, it has also made supply chains more complicated and harder to manage that has increased the supply risk. Christopher et al. (2011) note that supply risks are typically associated with the sourcing of products. However, it can be said that supply risks are more than just that as Manuj & Mentzer (2008a) divides supply risks to disruption of supply, inventory, schedules and technology access, price escalation, quality issues, technology uncertainty, product complexity and frequency of material design chances. According to them, supply risks can be defined as the movement of materials from suppliers' suppliers to the focal firm including reliability of suppliers, single versus dual sourcing, make or buy decisions, centralized versus decentralized sourcing and security issues. According to Lintukangas et al. (2016)

supply risks can be either direct or indirect. Direct risks relate to quality or price of the product or service whereas indirect risks concern property rights, brand and image and outsourcing. They have formed a summary of supply risks which is presented in table 2.

Table 2 Summary of supply risks (Lintukangas et al. 2016, 1903)

Supply risk	**Consequence**	**Risk mitigation tools**
Conflict of property rights	Loss of intangible assets	Legislation, contract, appropriability regimes, supplier relationship management
Damage in company reputation	Loss of sales, decrease of equity	Supplier relationship management
Unsatisfactory quality of purchases	Increase of after sales costs	Certification, auditing, controlling of suppliers
Rise of purchasing price and costs	Decrease of margin	Contract, financial instruments, inventory management
Outsourcing of critical activities	Loss of capability, increase of dependency on suppliers	Contract, supplier relationship management

Table 1 presents five essential supply risks, potential consequences and tools for risk mitigation. Olander et al. (2010) note that lack of a contract may cause conflicts relating to property rights especially in collaboration projects as suppliers might be for example interested in offering new innovation to its other customers for achieving greater revenues. This can give bargaining power to supplier and cause loss of trust and thus ruining important business relationship. As a consequence of outsourcing, suppliers' actions might damage the reputation of buying company. These effects can also be positive for example if supplier has strong reputation for innovation but negative spill-overs cause major risks and emphasize the meaning of risk

management. (Petersen and Lemke 2015) Christopher et al. (2011) present in their study that reduced lead times as well as insufficient supplier selection and auditing processes have mentioned to be main reasons for unsatisfactory of quality as suppliers do not have enough time or lack of competence to fulfill required quality. Holweg et al. (2011) point out that purchasing price and costs have increased steeply for example in many developing countries and as a consequence, buyers have been forced to switch suppliers that causes additional transaction costs. Lonsdale (1999) states that outsourcing of critical activities is a several risk because it causes strong dependency on suppliers and ignoring the effect of this risk has caused great costs to companies' competitive position.

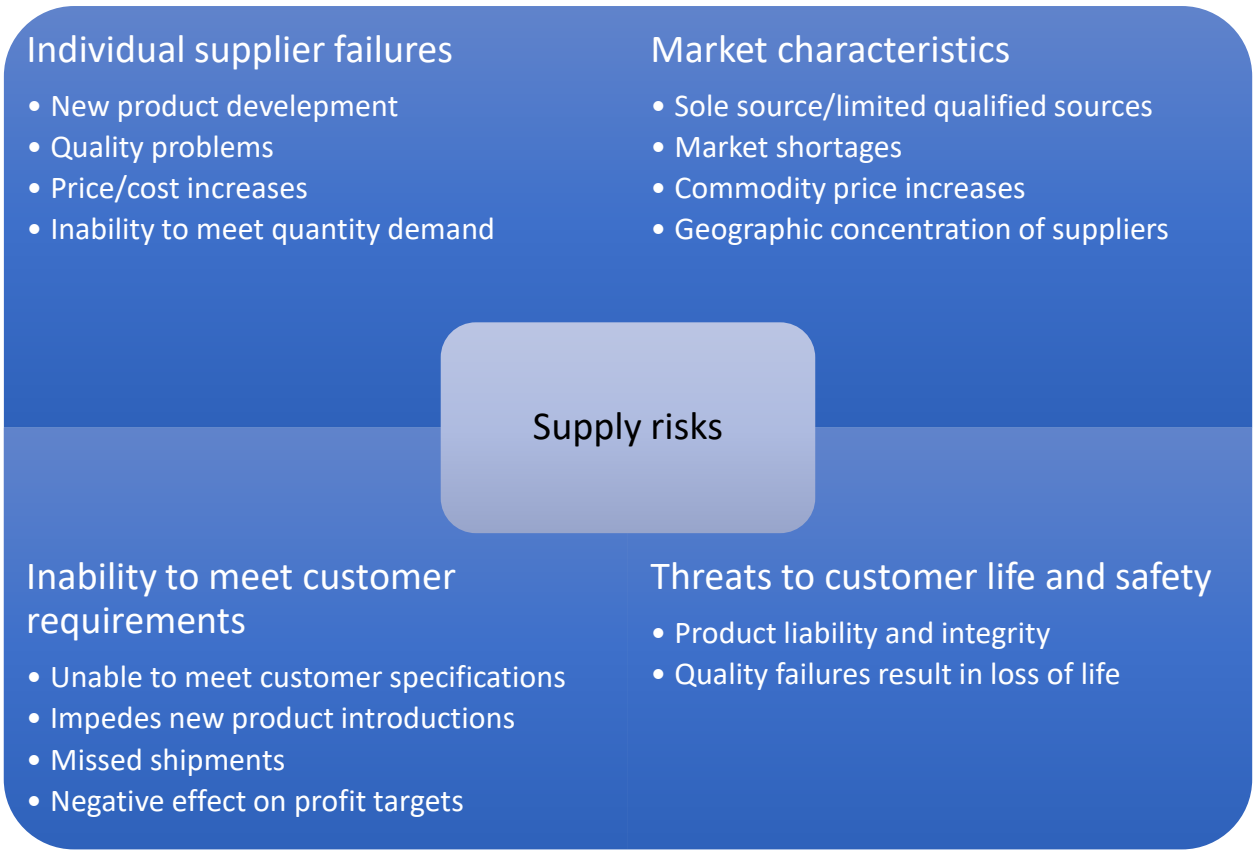

Figure 6 Classification of supply risks based on (Zsidisin 2003, 221)

Figure 6 presents more extensive classification of supply risks. Four main categories are individual supplier failures, market characteristics, inability to meet customer requirements and threats to customer life and safety. First two categories are concerning suppliers' capabilities to fulfill contracts and react to the additional requests of buying companies as well as solo sources and other market capacity

issues. On the contrary last two categories are related to the negative outcomes, especially meeting customers' requirements and threating their safety. (Zsidisin 2003) This classification includes partly same supply risks which Lintukangas et al. (2016) have presented but in addition there are multiple additional risk types under each category.

2.5 Supply risk management strategies

After going through steps of supply risk management process and identifying supply risks it is possible to assess proper supply risk management strategies. Hallikas & Lintukangas (2016) argue that there is a wide range of management actions which can reduce the impact and probability of identified risks in supply chains. Risk identification and assessment have important role in supply risk management process as they identify where to focus the actions. Part of risks can be managed in co-operation with suppliers but there are plenty of risks that must be managed by individual companies. (Hallikas et al. 2004) As mentioned earlier risk identification and mitigating are essential steps of supply risk management process and according to Hoffmann et al. (2013) identification of risk indicators and mitigation strategies can be used as management instruction for designing individual supply risk management systems.

Jüttner et al. (2003) discuss about four generic strategies for mitigating risks in supply chain that are 1) avoidance, 2) control, 3) co-operation and 4) flexibility. Avoidance can relate to specific products, geographical areas or suppliers if the buying company sees that supply is unreliable. Control concerns for example vertical integration, warehouse management and logistics whereas co-operation focus on joint efforts with suppliers to improvement projects and sharing risk related information. Flexibility in turn, deals with postponement, multiple sourcing and local sourcing. Postponement reduces companies' dependence on forecasts and increases ability to react on chances in demand. Multiple sourcing is a traditional action for spreading supply risk while local sourcing cut down lead times and increase ability for quick responses. Manuj & Mentzer (2008b) analyze further risk

management strategies based on research of Jüttner et al. (2003) and they recognize two new supply risk management strategies which are hedging and security. Hedging means having a globally dispersed supplier portfolio so that effects of single events minimize. For hedging it is characteristic that the advantage emphasizes when supply chain faces high risks as it requires high levels of investment. Security strategy is focused on tracking and monitoring transportation and identifying unusual or suspicious elements.

Table 3 presents four supply chain types and best suitable risk management strategies composed by Manuj and Mentzer (2008a). This model proposes to utilize single sourcing and postponement when the state of supply uncertainty is low while in more uncertainty supply environments it is more preferable use multiple sourcing, transferring risk and hedging.

Table 3 Supply chain types and risk management strategies (Manuj and Mentzer 2008, 146)

		Demand Uncertainty	
		Low	High
Supply uncertainty	Low	**Efficient Supply Chain** *Focus on Cost-efficiency* Postponement Single Sourcing	**Responsive Supply Chain** *Focus on Responsiveness and Flexibility* Postponement
	High	**Risk Hedging Supply Chain** *Focus on Pooling and Sharing Risks* Multiple Sourcing Transferring/Sharing Risk Hedging	**Agile Supply Chain** *Focus on Responsiveness and Hedging Risks* Hedging

Supply risk management strategies may include also supply chain partnerships, long-term financial arrangements or product/market portfolio development (Harland et al. 2003). Fang et al. (2013) propose that managers can make decision of using a backup supplier or an additional regular supplier to prevent risk of being

dependent on single supplier. However, if the backup supplier is not capable to supply with zero lead time, it is more efficient to use dual sourcing strategy. This statement is supported by Tang (2006a) as he notes that multi-supplier strategy is the most common strategy for reducing supply chain risks especially if suppliers are located in multiple countries. In addition, he states that using revenue or risk sharing contracts could increase resilience in supply chains.

Furthermore, there can be seen a connection between supply risk management and green supply management as Lintukangas et al. (2016) argues that supply risk management is related to green supply management and adoption of green supply management has an influence on companies' ability to mitigate different supply risks. They note that green supply management has connection with managing quality and brand/image issues, but it is not functional with price risks. However, green supply management offers interesting possibilities as managers must deal with price at the same time with environmental issues and this should be considered in supply management.

2.6 Business continuity planning

Companies have typically employed business continuity planning (BCP) for reducing risks and maintaining operational continuity under disruption events. Researchers have begun to pay more attention to utilizing BCP process to manage supply chain risks as late as in 2000s. (Ojha et al. 2013) Zsidisin et al. (2005) argue that BCP has been developed for minimizing the effects of unexpected disruptions that prevent companies to fulfill customers' expectations. Speight (2011) defines BCP as a strategy for promoting organizational resilience by strengthening organizations' capacity to persist and continue operations during a disruption. Public Safety Canada (2015) presents also corresponding definition since BCP can be seen as a proactive planning process which secures that critical services and products are delivered during a disruption.

Ohja et al. (2013) have analyzed earlier researches over BCP and few key findings are presented in table 4. Forbes (2009) notes that BCP must be considered as a significant part of supply chain risk management. This is supported by Norrman & Jansson (2004) as they state that companies must consider the trade-offs between risk management, quality, delivery time and cost performance of the supply chain for defining the optimal level of BCP. Likewise, Perry (2007) notified that supply chain BCP should include both internal and external stakeholders. Blos et al. (2010) identified in their study that BCP logic that combines risk management with organization's fulfillment capabilities can be used as a base of risk mitigation framework. Whereas Benyoucef & Forzley (2007), emphasized the importance of information technology for BCP process.

Table 4 Researches in business continuity planning based on (Ohja et al. 2013, 182)

Author	**Key findings**
Forbes (2009)	BCP is an integral part of supply chain risk management plans.
Norrman & Jansson (2004)	Companies should target the optimal level of BCP by taking into account the trade-off between risk management, quality, delivery time and cost performance of the supply chain.
Blos et al. (2010)	Developed a risk mitigation framework based on BCP logic that combines risk management with organizational capabilities.
Benyoucef & Forzley (2007)	Included an information technology component to broaden the Four-stage framework of BCP processes within supply chains.
Perry (2007)	BCP should be holistic and comprehensive effort that includes internal and external processes and partners.

Sheffi & Rice (2005) state that many companies leave risk management and business continuity to security professionals, business continuity planners and insurance professionals. This may be problematic as building a resilient company should be a strategic initiative that changes the way a company operates and also creates competitive edge. According to (Tracey et al. 2017), BCP bases typically on

predict and prevent approach. BCP is one of the main steps of business continuity management with risk assessment and business impact analysis (BIA). Before starting BCP phase, there must be conducted BIA and risk assessment. Benyoucef & Forzley (2007) point out that BCP is related to every function of the organization for ensuring that the business operations can be continued regardless of what kind of disruption happens.

Lindström & Hägerfors (2009) state that BCP is part of strategic steering instruments for senior management. However, it has been notified that BCP is often not cared properly as senior management does not understand the concept of BCP (Kajava et al. (2006). According to Speight (2011), BCP notifies all phases of a disruption as well as the tasks and strategies for risk reduction, readiness, response and recovery. BCP process consists of three elements which are 1) business impact analysis (BIA), 2) disaster consistency recovery plan and 3) test and training (Cerullo & Cerullo 2004). Melton & Trahan (2009) argue that it is important that risk management understand how BCP and insurance policy react to each risk type. According to Soufi et al. (2018), BCP should focus on mitigating the impact of identified disruptions on the key products. In addition, they point out that earlier literature has identified the importance of having convenient BCP for reacting against disruptions.

Implementing BCP to entire supply chain requires successful management of the supply chain. In some cases, this may demand spending significant amount of money on new technology but for most companies, a simple dialogue and effective communication between supply chain members produce often desired results. (Benyousef & Forzley 2007) However, Violino (2004) states that many companies do not understand the supply chain beyond their immediate suppliers. They point out that under 40 % of companies are sharing information between their suppliers regularly and almost 20 % do not share information at all. Benyousef & Forzley (2007) emphasize this notification by stating that if information is not flowing properly from suppliers to customers, company which is positioned in the end of the supply chain may have only limited visibility of the issues in earlier phases of the chain. As

a consequence, companies have less time to react to disruptions and the possible impact is bigger.

BCP is closely related to changes made in the organization. If BCP is implemented in the organization culture, it will become part of normal organizational practices. Hence, BCP is integrated into daily activities and if changes will be made, they must be updated into the BCP. In other words, it can be said that BCP is taken into consideration before making changes. (Tracey et al. 2017) This is supported by Adamou (2014) as he states, that a culture of preparedness and support of management is indispensable for full implementation of BCP practices. According to Lindström et al. (2010), IT- and information security is one of the most important issues in BCP. Information security is a central part of modern business management systems for creating competitive advantage that requires close co-operation between security experts and senior management (Anttila et al. 2004). However, Kajava et al. (2006) point out that senior management has typically only superficial knowledge of information security and only 20 percent of managers have realized the strategic value of information security.

Lindström et al. (2010) emphasize the role of training experiences. It is preferred to learn rather from training instead of learning from real experiences. The reason for this is that crisis management team should be ready to handle crisis before it realizes. They add that in case of disruption, real experience should be also utilized for developing BCP and the related training. Smith (2004) presents opposite point of view by stating that it could be better to utilize real experiences of other companies or separating involved individuals from the situation context for avoiding post-disruption blaming. For BCP, it is extremely important that the plan works in practice instead of only theory. In the ideal situation, organization knows BCP by heart and is able to solve all disruptions rationally without even opening the BCP. (Lindström et al. 2010) Reason (2000) points out that companies which implement BCP are aware of things that might go wrong. Similarly, Ohja et al. (2013) states that many companies are listing previous disruptions, what are their sources and the impact to the company. In addition, Carmeli & Schaubroeck (2008) note that earlier disruptions should be properly analyzed for unlearning adverse behaviors

and incorporating new behaviors. This helps companies to reduce organizational vulnerabilities. Furthermore, Benyoucef & Forzley (2007) point out that company's ability to recover from supply chain disruption depend on its supplier's ability to recover regardless of how good BCP process is. For this reason, expediting BCP to suppliers improves companies' possibilities to react for disruptions and thus provides clear competitive advantage.

2.7 Business impact analysis

As noted earlier, business impact analysis has a crucial role in business continuity planning. BIA process includes identifying the critical business functions, defining the impact of not performing functions and examining cost consequences (Devargas 1999). Torabi et al. (2014) state that BIA is a key part of business continuity management system. The BCP process should always begin with BIA as it sets the baseline for companies to plan their recovery strategies (Miller 2003; Sikdar 2011). Furthermore, Cha et al. (2008) note that business continuity management strategies should keep organization's key functions in operation based on the outcomes of BIA. Therefore, it can be said that the validity of BCP is depending on the results of BIA (Torabi et al. 2014).

BIA takes place before developing BCP and selecting business continuity management strategy. It is typically followed by recovery strategies, plan development, validation, maintenance and training. (Paunescu et al. 2018) According to Tjoa et al. (2008) the most important steps for BIA are identifying business activities and functions, recognizing suitable resources, identifying scenarios which are leading to severe impacts on the company's reputation, financial position of the company and identifying time-frames over which disruptions are not acceptable. Sikdar (2011) states that the main objective of BIA is to gather and analyze required information for creating a report for preparing BCP. Implementing process of BIA includes three steps which are data gathering, data analysis and report preparing (presented in figure 7). The process starts with gathering data for identifying critical and time-sensitive functions. Finally, these

functions will be analyzed based on their recovery time objectives and at last a report will be prepared for top management.

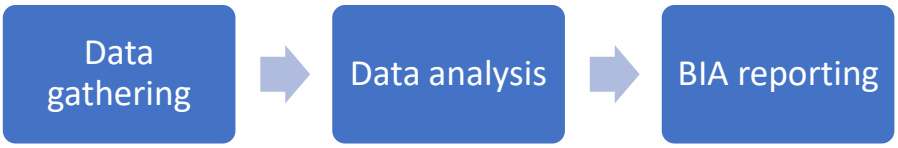

Figure 7 Phases of BIA based on (Sikdar 2011)

According to Wright (2011), BIA identifies the short-term impact of different business units and this information can be used to define to which units actions should be targeted. The results of BIA may be for example a statement of the number of not sold items during specific time-period or an estimate of the potential loss (Devargas 1999). Paunescu et al. (2018) point out that BIA focuses on identifying companies' critical processes and activities, including also critical resources for delivering key products or services to customers. Thus, it can be said that BIA is a tool that identifies processes that cannot stop, their priority and resources which are needed for performing those (Sikdar 2011). Devargas (1999) defines the purpose of BIA as follows: 1) identifying potential risks, 2) estimating the impacts of disruption to the whole organization, 3) defining the requirements for a recovery strategy that includes required resources, 4) providing the financial reasoning for disruption preparation and recovery activities, 5) defining the criticality of each business function for prioritizing their recovery, 6) assessing financial and operational impacts and quantifying those as accurate as possible and 7) determining schedule for recover of critical functions.

Tammineedi (2010) argues that the key objectives of BIA are: 1) determining the potential impact to the organization, 2) identifying critical products/services and maximum tolerable disruption period, recovery time objectives and recovery point objectives for those, 3) determining the order of recovering business functions and data of the disruption event and 4) identifying recovery strategies, minimum resources and required records for business continuity. Whereas Torabi et al. (2014) state that BIA process consists of three main steps which are 1) identifying key products, 2) identifying critical functions and 3) determining the continuity

measures of key products and their critical functions. It is important to identify key products since it is impossible to recover all processes related to all products after disruption and there must be a plan which products must be recovered first. Table 5 presents measures that may be used for identifying key products. According to Torabi et al. (2014), increased global competition between organizations makes reputation issues as important as loss of revenue and it must also be considered while defining key products. In addition, measures such as influence on markets, human resources and technologies help companies to form a holistic view on its products.

Table 5 Measures for selecting key products based on (Torabi et al. 2014)

Measures	**Author**	**Short description**
Loss of revenue	Nosworthy (2000), Ernest-Jones (2005)	Lost revenue because of manufacturing breakdown.
Loss of interested parties supports	Ernest-Jones (2005)	Lost interested parties' support because of manufacturing breakdown.
Defection of customers	Nosworthy (2000), Ernest-Jones (2005)	Loss of customers' demands because of manufacturing breakdown.
Higher insurance costs	Ernest-Jones (2005)	Higher compensation costs because of manufacturing breakdown.
Degree of damage on company's image and reputation	Nosworthy (2000), Ernest-Jones (2005)	Company is famous for manufacturing products, unavailability of them will damage the reputation.
Influence on human resources	Niazi et al. (2006), Hung et al. (2005), Nosworthy (2000)	Degree of losing market share because of manufacturing breakdown
Loss of the technological level of company	Abdel-Razek (1997)	Manufacturing breakdown damages ability to develop products.

As BIA is management-level assessment of financial and operational impacts, it presents possible result of business disruption (Miller 2003). Messer (2009)

presents a series of measurements which can be utilized for measuring criticality of each function. Measurement bases on self-ranking of each function and the results help to identify which processes are most critical and hence what need to be recovered first. This model consists of six categories which are illustrated in figure 8. Financial effect illustrates the monetary impact of function's unavailability for defined time periods. Legal requirement demands verifying if the function need to meet any regulatory or legal requirements. Customer impact deals with customers' ability to have business with the company whereas stakeholder impact focuses on analyzing if the function relates to stakeholders or brand recognition via media. Dependency impact in turn examines if the function is critical for another required process. At last, vulnerability impact considers if the function is done in a single location and what are redundancy and recovery capabilities. Based on these measurements, it is possible to identify which functions are mission-critical and require most attention.

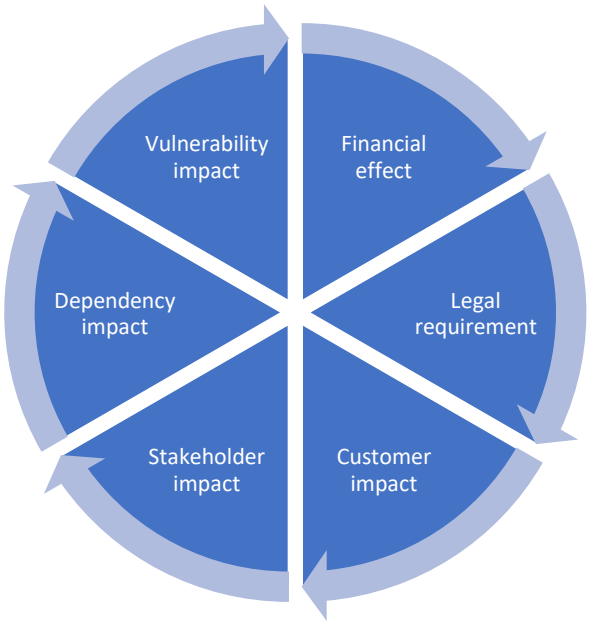

Figure 8 BIA measurements based on (Messer 2009)

Soufi et al. (2018) point out that BIA process is similar for manufacturing and service companies, but the difference is in used measures for determining key products and critical functions. Paunescu et al. (2018) note that BIA identifies and evaluates possible effects of disruptions to the business operations such as financial, safety,

contractual, reputation and image. According to Tammineedi (2010), BIA should be conducted with assumption of the worst-case scenario that affects to majority of business function for providing proper view on the relative importance of different business functions and processes. BIA is focusing on the effect rather than the events behind the effect. As BIA highlights possible costs and losses related to disruption event, it helps gaining management support for BCP (Miller 2003). This can be seen to one of the most important advantages of BIA. Messer (2009) emphasizes that companies should aim for determining the true impact to the business and how to sustain the critical functionality. Companies are typically utilizing geographic or standalone functional view of the world in the BIA process. This means that if there are multiple buildings or locations, all of them are evaluated individually. Furthermore, if there are multiple functions in one facility, companies must evaluate the impact on the business of the facility and all of its functions. Otherwise, there is risk to overlook relationships between different functions and fall into utilizing all or nothing recovery strategy.

3. Supply chain disruptions

This chapter focuses on supply chain disruptions. There exist many different risks in our daily life such as being hit by a car or cutting finger while cooking. However, people are willing to take these risks and accept these consequences because of their benefits. In a same way, it is impossible to succeed in business life without standing risks. Companies must accept that risks exist and develop risk mitigation strategies for getting a competitive advantage. (Kirilmaz & Erol, 2017) Bode et al. (2011) point out that global competition has led to forming tight interfirm networks where disruptions in material, information and fund flows have become a norm. Chopra, Reinhardt & Mohan (2007) states that if companies ignore supply risks, it may lead to overutilization of cheaper and unreliable suppliers while utilization of reliable suppliers decrease. This can cause several costs to companies as lack of materials may shut down the whole production. In addition, supply chain disruptions can reduce operational performance, profitability as well as shareholder value significantly over long-standing (Hendricks & Singhal 2003). The importance of supply chain disruptions is globally notified as a report from World Economic Forum (2008) nominates supply chain disruptions as one of the four significant emerging issues along with systematic financial risk, food security and electric security.

3.1 Defining supply chain disruptions

Most widely used definition for supply chain disruptions comes from Craighead et al. (2007) as they have described those as unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain. According to Bode et al. (2011) supply chain disruptions are interorganizational phenomena that require at least two companies engaged in a relationship and triggers for disruptions include for example supplier quality problems, delivery failures and plant fires. Gaonkar & Viswanadham (2004) in turn define supply chain disruptions as radical transformations in the structure of the supply chain through the non-availability of certain production, warehousing and distribution facilities or transportation due to

unexpected event that is caused by human or nature. Another definition is presented by Bode & Wagner (2015) as they argue that supply chain disruption can be seen as the combination of unintended and unexpected launching event that comes up somewhere in the upstream supply chain, the inbound logistics network or the focal company's purchasing environment and a remarkable situation which causes a serious threat to the business operations of the focal company. This definition covers a large set of issues such as quality problems with suppliers, delivery outages, supplier defaults, labor strikes and plant fires. Supply chain disruption can be also defined as unforeseen events that have negative effects on the normal flow of materials through the supply chain (Ellis et al. 2010, Craighead et al. 2007). According to Kim et al. (2015), supply chain disruptions are increasingly studied topic and most of studies have focused on assessing vulnerabilities that companies face as well as how they can manage these vulnerabilities. It is typical that disruptions such as stoppages of material flows originate from supply network instead of the focal company's facilities. It is also important to notify that disruptions on local level do not automatically interrupt operations on network level.

As noted earlier, supply chain management is pursuing to secure uninterrupted flow of direct materials from suppliers. According to Ellis et al. (2010), it has become more difficult for buying companies to reach this goal since companies are sourcing increasingly important direct materials with more complex supply chains. Consequently, this increases the probability of supply chain disruptions and supply risks. Supply chain disruptions in turn originate from vulnerabilities of interconnected material flows, information and funds between members of supply chain. Revilla & Sáenz (2014) point out that as supply chains expand overseas, they will face increased need for managing supply chain disruptions from a cross-national perspective. It can be seen that long and complex supply chains that work with increasing speeds, are ground reason behind supply chain disruptions. Kirilmaz & Erol (2017) point out that companies' intentions to shorten lead times of supply chains, by utilizing popular trends such as lean manufacturing, improving optimization techniques and shortening of product life cycle increase the number of supply chain risks. All members in a supply chain have their own individual objectives and their collision may increase the risk of another member. However, if

disruption occurs in one step of the supply chain, it has negative effects for all members. Papadakis (2006) states that make-to-order supply chains are more vulnerable for disruptions than make-to-forecast supply chains. Stecke & Kumar (2009) note that today's business environment focuses on increasing efficiency and decreasing costs. As a result, supply chains are effective under normal circumstances but their vulnerability to disruptions has increased at the same time.

Sheffi & Rice (2005) present eight stages of disruption that are typical for significant disruptions (figure 9). This model can be used to characterize the nature of the disruption and the dynamics of company's response.

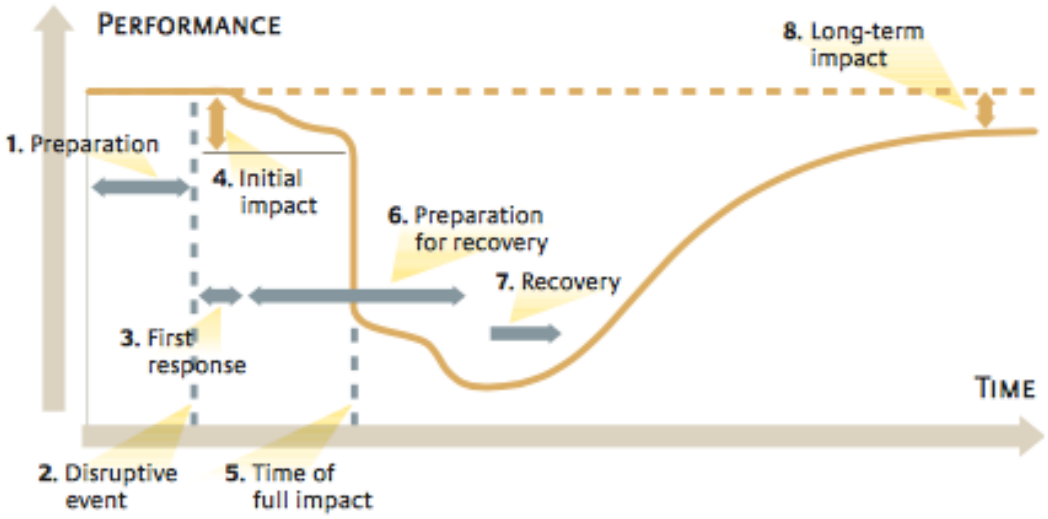

Figure 9 Stages of disruption (Sheffi & Rice 2005)

First stage, preparation, describes if the company can foresee the disruption and has time for preparing and minimizing its effects. Disruptive event in turn, illustrates the type of disruption such as tornado, bomb explosion, supplier bankruptcy or strike. Following first response is aimed at leading the situation, protecting lives or preventing further damages depending on the type of disruption. The state of initial impact depends on factors such as the extent of the disruption, available redundancy and the inherent resilience of the company and its supply chain. Therefore, it is typical that performance starts to decrease during the time between the disruptive event and the full impact. Full impact may occur immediately or

delayed but it causes often significant drop of performance. Preparation for recovery starts often at the same time with first response stage and sometimes even before the disruptive event if it has been foreseen. Recovery preparations may include qualifying new suppliers and redirecting suppliers' resources, finding alternative transportation modes and searching for alternative parts that could be used in the production. Recovery aims for getting the company back to normal operation level. Usually, companies try to make up for lost production by using higher capacity than normally, by using overtime work or resources of suppliers and/or customers resources. Recovery from disruptions take usually time and especially if customer relationships have been damaged, there can be seen long-term impacts that make recovery more difficult. An example of the significance of customer relationship can be seen in Japan where the network of small-scale shoe factories in Kobe lost 90 % of its business because of earthquake which stroke to the city in 1995. As a consequence, buyers shifted to other Asian factories and most of them never returned. (Sheffi & Rice 2005)

3.2 Supply chain complexity

Supply chain can be defined as a complex network of companies that are involved in upstream and downstream flows of materials, finances and information (Mentzer et al. 2001) Wiengarten et al. (2016) state that companies have found multiple global production practices for responding to opportunities and threats of globalization. However, these have increased supply chain complexity and forms of risks. According to Bode & Wagner (2015), supply chain complexity is a central concept relating to supply chain disruptions. Supply chains have become more complex over the last decades and that this causes challenges for companies. These challenges may appear as decreased operations' performance, more complicated decision making and increased quantity of disruptions. Supply chain complexity is typically viewed as multi-faced, multi-dimensional phenomenon that is driven by several sources such as uncertainty, complicatedness and technological industry. It can be said that trends such as globalization, sustainability, outsourcing and flexibility accelerate the growth of supply chain complexity (Serdarasan 2013). Gaonkar &

Viswanadham (2004) note that because of supply chain complexity, companies must look for safely mechanisms to protect against disruptions. Companies can for example expedite orders, check order status frequently, utilize just-in-case inventory and add safety margins to inventory.

Increased supply chain integration has caused that companies must deal with increased level of complexity. It has been notified that supply chain integration is a key practice that can be used for managing supply chains. (Wiengarten 2016) This is supported by Schoenherr & Swink (2012) as they state that companies are managing supply chain complexity through closely integrated supply chains. Supply chain integration in turn, can be seen as the extent how deeply companies strategically interconnects and aligns their supply chains with their partners. It has been identified that supply chain complexity has direct increasing effect on the impact of supply chain disruptions. Supply chain complexity does not slow down the response speed when disruption occurs. Instead, increased complexity makes it more difficult to recognize and diagnose the disruption. In complex supply chains, it is typical that especially diagnosis of disruption is the bottleneck which slows down recovery. (Bode & Macdonald 2017) However, Lu & Shang (2017) argue that effects of complexity are not always negative. Instead, in case of individual complexity dimension, it may have also positive effects. Complexity dimensions have different impacts and thus, the overall effect depends on the magnitude of the complexity dimension itself.

Bode & Wagner (2015) point out that there can be seen two specific methods how complexity affects to the probability of supply chain disruptions. First one is the emergence of disruptive effects which means that the more potentially disruptive elements there exist in the supply chain the higher the probability of supply chain disruptions is. Thus, it can be said that large supply chains have higher risk of disruptions than smaller supply chains. The second method is managerial ability to detect and prevent disruptive events either prior or shortly after their incident. Many disruptions send out warning signals beforehand and if these signals will be detected and correctly interpreted, it is possible to avoid or reduce damages. However, it is important to understand that there are more elements in larger supply

chains which may cause disruptions that makes it more difficult to identify warning signals. Serdarasan (2013) emphasizes that it is important to characterize the supply chain complexity and analyze what are the drivers behind it. This allows developing a clear strategy for managing supply chain complexity.

Serdarasan (2013) argue that supply chain complexity is divided into static, dynamic and decision-making distinctions. Static complexity focuses on the structure of the supply chain and its components. Dynamic complexity describes the uncertainty in the supply chain involving also aspects of time and randomness as well as interactions of elements which define the system. (Bode & Wagner 2015, Serdarasan 2013) Decision-making distinction in turn includes both static and dynamic aspects of complexity. Supply chain complexity drivers can be classified based on their origin as well. There exist three groups which are internal, supply interface and external drivers. Internal drivers are related to decisions and factors within organizations such as design of products and processes. These are relatively easy to manage because they are under control of companies. Supply interface drivers concern material and information flows between suppliers. Also, drivers in this group are manageable but it depends on the level of coordination between supply chain members. For this reason, power and trust mechanisms have significant role when considering supply interface drivers. External drivers instead, are group on which company has only little if any control over. For example, regulation, market trends and other environmental factors are affecting to the supply chains. These two classifications are presented in table 6 below. In addition, it is important to notify that each driver may have either positive or negative effect on another driver because of supply chain's nature. This property can be used for transferring complexity from one driver to another which is under control of the company. (Serdarasan 2013)

Table 6 Drivers of supply chain complexity based on (Serdarasam 2013)

	Internal	Supply interface	External
Static	- Number of products - Number of processes	- Type of product - Number of suppliers - Process interactions - Conflicting policies	- Customers' needs change - Resource requirements change - New technologies
Dynamic	- Lack of control over processes - Process uncertainties - Employee related uncertainties	- Lack of process synchronization - Parallel interactions	- Changes in geopolitical environment - Short product lifecycles - Market uncertainties - Future developments
Decision-making	- Organizational structure - Decision making process - IT systems	- Differing/conflicting decisions and actions - Non-synchronized decision making - Information gaps - Incompatible IT systems	- Changes in environment - Uncertainty of the uncontrollable factors

According to another classification, supply chain complexity can be divided into horizontal, vertical and spatial complexity (Choi & Hong 2002; Lu & Shang 2017). Horizontal complexity is related to the quantity of suppliers in each tier of supply chain. It bases on an assumption that there does not exist any perfectly reliable supplier and the frequency of disruptions will probably increase with the quantity of direct suppliers. The severity of these disruptions is though related to selected sourcing strategy (single-, dual- or multi-sourcing). There can be seen an interesting notification that use of dual- or multi-sourcing will increase horizontal complexity and quantity of disruptions but at the same time it can reduce the severity of disruptions. (Choi & Hong 2002) Horizontal complexity increases especially communication costs as the number of suppliers grows. Nevertheless, this may reduce the risk of supply chain disruption as supply base has higher redundancy. (Lu & Shang 2017) Holcomb & Hitt (2007) have made similar notification as they that that benefits of

broad supply base are higher than increased communication and monitoring costs as long as the number of suppliers can be managed.

Vertical supply chain complexity instead, bases on hierarchical levels since the more tiers of suppliers there exist, the greater complexity related to the supply chain is (Blackhurst et al. 2005; Bode & Wagner 2015). If supply chain includes multiple tiers, it will be more difficult to supervise suppliers and suppliers' sub-suppliers may cause several damages for the focal company (Bode & Wagner 2015). Choi & Hong (2002) point out that focal companies have typically only limited visibility to their supply network behind their first-tier suppliers. This makes it extremely difficult to identify what kind of risks there exist on lower-tiers of supply network. High vertical complexity makes it difficult to specify product attributes and integrate process phases with members of supply chain (Lu & Shang 2017). Bode & Wagner (2015) state that if vertical complexity is too high, it may cause multiple disruptions to the buying company. Furthermore, increased vertical complexity has direct impact on information asymmetry that is typical in hierarchically distant supply chains. However, also vertical complexity may have positive effects as point out. According to Flynn et al. (2010), buying company may benefit from suppliers' unique knowledge for enhancing its business performance. Specialized suppliers may achieve smoother production and better economics of scale. Thus, sourcing from specialized suppliers may be more efficient than inhouse production. (Lu & Shang 2017)

Spatial complexity makes the structure of the supply chain more complicated and it originates from the geographical spread of the company and/or its supplier base (Bode & Wagner 2015; Vachon & Klassen 2002). Von Corswant & Fredriksson (2002) point out that spatial complexity is typically measured by the number of countries where focal company's suppliers locate. Utilization of global sourcing is often related to high levels of spatial complexity in the upstream supply chain. If supply chain is geographically dispersed, goods move longer paths, involving more logistics touch points such and greater resilience of critical infrastructures. This increases vulnerability of risk sources such as cargo theft, rough handling and environmental conditions. (Bode & Wagner 2015) It can be seen that geographically

dispersed supply chains face challenges with knowledge asymmetries as well (Lu & Shang 2017). In addition, Bode & Wagner (2015) point out that there can be seen that need for information processing and monitoring costs increase when geographical distance between buying company and suppliers grows. These difficulties may base on for example time zone and language differences and even though technology reduces costs of information change and monitoring, companies have still difficulties in supervising remote suppliers. According to Vachon & Klassen (2005) widely spread supply base causes difficulties in coordination production because of higher complicatedness. Conversely, broad supply base allows access to global knowledge, cheaper materials and labor (Gilley & Rasheed 2000).

Bode & Wagner (2015) states that all of these complexity types increase the quantity of supply chain disruptions. However, there can be seen that horizontal and spatial complexity might increase their quantity more than linearly. They also point out that there exists a strong synergy between these three complexity dimensions. This makes it important to take all the dimensions of complexity into account for reaching complete picture of the frequency of supply chain disruptions. Lu & Shang (2017) instead state that horizontal and spatial complexity relate to especially financial performance whereas in case of vertical complexity, for example a deep upstream supplier has only limited impact on the focal company's financial performance.

3.3 Main disruption risks

Earlier researches argue that the supply chains have become more vulnerable to disruptions during 2000s (Christopher & Lee 2004; Craighead et al. 2007; Kleindorfer & Saad 2005). There exist multiple different methods for classifying supply chain disruption types. According to Sheffi & Rice (2005) supply chain disruptions can be divided into three groups which are unexpected events (including natural disasters), accidents and intentional disruptions such as job actions, terrorism and sabotage. Also, Banham (2014) presents similar classification as political, economic and natural hazards are central risk in the era of lean manufacturing, global sales and international supply chains. Allianz Global

Corporate & Specialty (2015) present in their report that top 10 causes of supply chain disruptions between 2010-2014 were:

1. Fire and explosion
2. Storm
3. Machinery breakdown
4. Faulty design/material/manufacturing
5. Strike/riot/vandalism
6. Cast loss (entertainment)
7. Flood
8. Collapse
9. Human error/operating error
10. Power interruption

Fire and explosion form the largest group as they have caused 59 % of interruptions whereas second largest groups, storms and machinery breakdown, have caused only 6 % and 5 % of interruptions during monitoring period. There can be seen differences regionally and for example in Asia storms and floods are causing multiple disruptions. The monetary impact of disruptions has also been growing in Asia hence the economic power of China has risen. There have also been noted that almost 90 % of all disruptions result from technical or human factors instead of natural catastrophes. (Allianz Global Corporate & Specialty 2015) Gaonkar & Viswanadham (2004) present examples of supply chain disruptions directed to different functions that are presented in table 7. Companies must consider these scenarios and choose a set of suppliers that minimize the expected supply shortfall.

Table 7 Examples of supply chain disruptions

Mode of Disruptions	**Description**
Supply side	Delay or unavailability of materials from suppliers, leading to a shortage of inputs that could paralyze the production.
Transportation	Delay or unavailability of either inbound or outbound transportation to move goods due to carrier breakdown or weather problems.
Facilities	Breakdown of machines, power or water failure leading to delay or unavailability of plants, warehouses and office buildings.
Breaches in freight or partnerships	Violation of the integrity of cargoes, products (can be due either to theft or tampering with criminal purpose, e.g. smuggling weapons inside containers) or company proprietary information.
Failed communications	Failure of information and communication infrastructure due to line, computer hardware or software failures or virus attacks, leading to the inability to coordinate operations and execute transactions.
Wild demand fluctuations	Sudden loss of demand due to economic downturn, company bankruptcies, war etc.

Sources of supply chain disruptions may be classified based on their role in the supply chain as either inbound or outbound risk sources (Svensson 2002). Another perspective categorizes disruptions based on their nature such as natural hazards, man-made disasters, supply risks, forecast, inventory and capacity (Chopra & Sodhi 2004) Ellis et al. (2011) Zsidisin & Wagner (2010) Whereas Rao & Goldsby (2009) identify three sources for supply chain disruptions which are market, operational and environmental risks. Revilla & Saenz (2014) point out that based on previous researches most relevant sources of supply chain disruptions are market, supply chain discontinuity, natural hazards and socio-economic issues. According to Rao & Goldsby market issues are typically related to specific market segments or industry such as price or sale collapse due to competition. Supply chain discontinuity in turn means delivery or transportation failure whereas natural hazards can be seen as external sources (Kleindorfer & Saad 2005, Rao & Goldsby 2009). At last socio-economic issues have impact on the overall business context across industries such as political or economic instability. This definition of main supply chain disruption

sources made is supported by Kleindorfer & Saad (2005) as they point out that there can be identified three main groups of supply chain disruptions which are 1) operational disruptions, 2) natural hazards and 3) political disruptions. For this reason, this classification is used in following chapters for taking a closer look into main disruption sources.

3.3.1 Operational disruptions

Keindorfer & Saad (2005) argue that operational disruptions consist of equipment malfunctions, systemic failures, unexpected discontinuity of supply, such as bankruptcy or other less severe financial problems, and human-centered issues varying from fraud to strikes. According to Mizgier et al. (2015), operational disruptions originate either from internal sources such as processes, systems and employees or from external events. Triggers of these disruptions are associated with raw materials, people, technology or another external event and these may cause significant operational losses. Sheffi & Rice (2005) note that in ideal situation, supply chains recover from operational disruptions quickly for maintaining the continuity of operations and company's position in the competitive landscape. However, supply chains will not typically recover quickly from operational disruptions as Hendricks & Singhal (2005) point out. Evaluating existing resilience capabilities has an important role since otherwise companies will be reluctant to invest in initiatives which could enhance resilience and remain vulnerable to operational disruptions (Tang & Tomlin 2008). In addition, Mizgier et al. (2015) note that there can be seen differences between industries and companies must understand the inherent complexity and dynamism of their industry. As an example, operational disruptions may cause higher losses in the manufacturing sector than in the service sector.

Suppliers' financial risks and bankruptcies are serious threats for buying companies (Valadares de Oliveira & Handfield 2017). According to Swinney & Netessine (2009), it has been proved that suppliers' financial health is important for buying companies and that collaborative relationships produce benefits also to suppliers.

Financial problems at one company may impact on rivals which operate in the same product market as well as its customers and suppliers through the supply chain. There can be identified multiple indirect costs relating to financial problems. First, financial distress of buying company may increase the risk of supply chain disruptions as suppliers can decline trade credit, back away from long-term contracts or delay shipments. Whereas, in case if suppliers suffer financial problems, buying companies may need to wary of product quality, reduced value of warranties, continuity of supply and serviceability as well as impose costs by shifting purchases to existing or new suppliers. (Hertzel et al. 2008) Therefore, open communication especially with key suppliers is extremely important for proactively mitigating supply chain disruptions (Valadares de Oliveira & Handfield 2017).

Bankruptcy of a supplier may have multiple consequences for the buying company. If supplier terminates its operations, the buying company must switch to a new supplier which might be more expensive. At other extreme, if supplier is able to continue operations, it might though require financial support from the buying company. (Swinney & Netessine 2009) According to Hertzel et al. (2008), financial distress and risks of bankruptcies are typically widely known and thus, both suppliers and customers try to protect themselves against negative effects.

Swinney & Netessine (2009) examines suppliers' financial problems from the perspective of short- and long-term contracts. There can be seen three alternative cases that the buying company may face if supplier suffers from financial problems under short-term contracts. In the first case, supplier survives from its problems and the buying company decides to continue with that supplier in the second period. This scenario occurs if total costs of first period are small and supplier's idiosyncratic costs are low. In the second case, supplier also survives but the buying company chooses to switch supplier. This takes place if total costs are small, but supplier's idiosyncratic costs are large. In the third case, supplier goes bankrupt and the buying company is forced to switch supplier, and this occurs if total costs of first period are high. The buying company defines the size and shape of these regions based on offered prices and supplier's switching costs. Long-term contracts instead, restrain possibilities of the buying company to switch suppliers as it happens only in

case of supplier's bankruptcy. Hertzel et al. (2008) states that customers suffer rarely significant contagion effects from suppliers' financial problems. Instead, they may anticipate the situation and also be the initiator of supplier's financial distress. Because operational disruptions are exceptional, many companies have not faced such failures and there are challenges in mitigating these disruptions. Companies can choose between two strategies for mitigating operational disruptions. First one is process improvement which may base on utilization of data collected from other companies in the industry while second one is maintaining a capital charge to cover losses which arise from potential operational disruptions. (Mizgier et al. 2015)

3.3.2 Natural hazards

Natural hazards such as floods, hurricanes and earthquakes may cause significant disruptions to supply chains as they impact both manufacturing and logistics. Examples of these kind of impacts are series of hurricanes in Florida in 2004 and Kobe earthquake in Japan in 1995. (Kleindorfer & Saad 2005) Unlike in case of operational disruptions, the probabilities of natural hazards can be estimated based on historical data (Sheffi & Rice 2005). However, Haraguchi & Lall (2015) argue that that the impact of natural hazards is increasing on the global supply chains. Sutter & Smith (2017) note that critical shortages of many products which have been normally available before disruptions can be seen as the major consequence of natural hazards. In addition, it is typical that the prices of products will rise as relationship between supply and demand changes due to disrupted supply. According to Bakshi & Kleindorfer (2009), supply chain managers have become more aware of the consequences of natural disasters. This bases on increased complexity of supply chains and exposure to these events in global supply chains. In addition, Altay & Ramirez (2010) note that costs of natural disasters increase as the density and complexity of supply chains grow.

Recent business trends emphasize the role of efficient production and transportation system that increase cost efficiency and capital intensity. However, this exposes the entire systems for disruptions and break downs because of natural

hazards. (Haraguchi & Lall 2015) The risk of natural hazards relates directly to the location of country (Revilla & Sáenz 2014). It is typical that natural hazards are disturbing both domestic and global supply chains (Park et al. 2013). Companies should take the type of disaster into account while conducting mitigation plan as the consequences of for example windstorms and floods are significantly different compared to earthquakes. Climatic events are predictable, and companies have typically time to prepare for those, whereas earthquakes do not give any warning and might destroy national or company infrastructure. For this reason, it is very slow to recover from earthquake. Natural disasters affect to all members of supply chain and thus, companies that are not prepared for disasters will disrupt operations of the whole supply chain. Even though natural disasters are typically low-probability events, there are significant geographical differences due to climate and location of countries. Mudslides in Philippines, hurricanes in the Atlantic, earthquakes in Aegean Sea and sandstorms in North Africa are examples of these geographical characteristics and companies should consider higher probability of natural hazards and plan accordingly if they are considering outsourcing from these regions. (Altay & Ramirez 2010) Nevertheless it can be seen that companies do not prefer mitigation against natural hazards as Zsidisin et al. (2004) point out that only one of five studied companies gave importance to supplier's location on area with low change of natural hazards.

Hurricanes Katrina stroke in the Gulf Coast in 2005. It was followed by massive floods in New Orleans and together these had significant negative effects on companies' financial performance as well as performance of other member of supply chains. (Skipper et al. 2010) Wagner et al. (2014) note that for example in the Gulf Coast there are regularly exposed two major hurricanes per season. Furthermore, hurricanes are typically located on specific areas that makes it easier to forecast them and plan mitigation activities. Depending on the severity of hurricane, impacts can be seen over multiple months. From supply chain perspective, possible impacts of hurricanes can be seen to be related to disturbing the normal flow of material and services (Craighead et al. 2007). Ehlen et al. (2014) point out that consequences are typically directed to plants, transportation routes and other infrastructure such as ports. For example, in oil industry where security rules are extremely tight, supply

chain disruptions because of hurricanes are related to inspecting and repairing both producing platform and the pipeline network where it is integrated in. This demonstrates the extent of possible impacts of hurricane. However, it has been observed that only major hurricanes have economic impact. (Wagner et al. 2014)

On March 11 in 2011, a massive earthquake stroke in Japan followed by tsunami. Together these caused one of the costliest calamities in modern history causing damages of 235 billion dollars expressing the severity of natural hazards. The consequences of the earthquake and tsunami were worldwide since Japan is for example world's largest supplier of silicon and flash memories. (Park et al. 2013) Whitney et al. (2014) and Bradley (2014) illustrate that earthquake may cause disruptions from weeks to multiple months by damaging suppliers' facilities and equipment. In addition, earthquakes may cause significant damages to local infrastructure relating to indirect disruptions. Matsuo (2015) presents that the impact may be delayed as production stops when inventory is empty if company cannot find alternative supplier. It is also typical that there are difficulties to obtain necessary information over suppliers' status and new bottleneck suppliers may be revealed after the earthquake. Thus, lack of the information is seen as the main consequence of earthquake with direct impacts. Fujimoto & Park (2014) add that earthquake relates to multiple companies in the area. It is noted that if the focal company has multiple suppliers located in this area, the impact has potential to be significantly higher.

Fire in a plant is another central disruption related to supply chains and in this paper, it will be considered along natural hazards. If supplier's plant experiences a fire that shuts down its production, it will have negative effects on one or more companies on the following level of the supply chain. In worst case, if supplier has a critical role, shut down of plant could shut down the whole supply chain. (Blackhurst et al. 2018) On March 2000, a lightning strike caused a fire at a plant owned by Royal Philips Electronics that damaged millions of microchips. Nokia and Ericson were both customers of the Philips plant, but consequences of fire differed significantly. Nokia started to switch orders to other Philips plants and implement new suppliers almost immediately. This multi-supply strategy and quick reaction led to only minor

production problems. Whereas, Ericsson used single-sourcing strategy and shut down of Philips' plant disrupted production for months and caused 400 million dollars lost in sales. For preventing such losses managers must decide how to balance inventory, capacity and other elements across the entire supply chain even though dynamic and fast-changing environment compose challenges for this. (Chopra & Sodhi 2004) In addition, it is possible to prepare for plant fire by investing to warning and recovery capacity by installing fire alarms and sprinkler systems which prevents the fire from spreading quickly (Craighead et al. 2007).

3.3.3 Political disruptions

In addition of physical risks, risk managers should consider also possible impacts of political instability. According to Banham (2014), there have experienced political instability for example in Ukraine and Egypt during recent years that has made these countries questionable places to do business. In addition, economic factors such as rising interest rates in the United States may cause political and economic damage in emerging countries. Weiss & Azaran (2007) note point out that political disruptions originate from differences in legislation towards intellectual property rights, workforce contracting and employee laws. Olson & Wu (2011) point out that for example in China where market economy is not based on democratic politic system, there is some political risk if government interface with free companies. However, changes in political environment that do not have impact on economic environment, are not source of political disruptions (Hansen et al 2017).

Country risk relates closely to political disruption risk and according to Goodman & Ramer 2007), the role of country risk analysis is emphasized especially when making offshoring engagements. Kauppi et al. (2016) note that detailed vulnerability assessment relating to specific supply chain may be difficult and time-consuming, but it is possible to utilize third-party information on country risks. Thus, companies should be aware of disruptions risks which attend in their environment. According to Suder & Czinkota (2005), the role of location emphasizes if supplier do not have clear competitive advantage or core competencies. In this case, location factors

such as labor, land and low political risk increase its specific advantages abroad. It has been seen that investments are focused on less risky countries whereas countries with higher risk require more extensive capital investments. This in turn, triggers a downward spiral of competitiveness in those countries where political disruptions have higher probability. Hansen et al. (2017) point out that local bureaucracy is one of the highest single risks in host country environment along with clearance procedures, delays in approval process and licensing practices. In addition, corruption and organized labor strikes are mentioned as important sources of political disruptions. Corruption concerns mainly low-level operations instead of strategic issues whereas labor strikes may impact for example on suppliers' production ability or transportation infrastructure.

Another central disruption type in this category is terrorism. Suder & Czinkota (2005) point out that terrorism is considered as fourth-ranked policy concern in Europe, Asia and the Americas. Terrorism can impact in supply chains either directly or in conjunction with other effects such as new local policies or deteriorating macroeconomic indicators. World Trade Center attack in 9/11/2001 is the most remarkable event in category of political disruptions and it led to closing of U.S. borders and shut down all incoming and outgoing flights. One of the sufferers was Ford Motor Co. that had to idle multiple assembly lines since component deliveries from Canada and Mexico were delayed. Lack of materials decreased Ford's fourth-quarter output 13% compared with production plan. (Sheffi & Rice 2005) However, political disruptions include also sabotage, destructive competitive acts and political instability. It has been noted that these kinds of risks have increased in different countries during recent decades. This has emerging impact on supply chains as utilization of global outsourcing has increased and thus both length and complexity of supply chains have increased as well. (Kleindorfer & Saad 2005) Nevertheless, it is difficult to estimate probability of intentional disruptions such as job actions, terrorism and sabotage since they are designed to inflict maximum damage and company's decisions and actions may be their trigger (Sheffi & Rice 2005).

3.4 Impacts of supply chain disruptions

According to Bode et al. (2011) supply chain disruptions may have both direct and indirect negative impacts. Supply chain disruptions have a potential to cause significant impacts on the economic performance of companies and entire supply chains regardless the type of the disruption. The impact of supply chain disruption expresses that companies do not have control over exchange relationships, and they are unable to protect themselves against the inherent uncertainty. It is typical that the more serious the impact of supply chain disruption is, the more buying company's dissatisfaction with supplier increases (Primo et al. 2007). Sheffi & Rice (2005) present two different examples of widely known disruptions. First one is West Coast port lockout in 2002 that cost 1 billion dollars per day in the first week and 2 billion dollars per day in the second week. Lockout stopped container flows through the 29 West Coast ports causing disruptions to several companies. Another example is foot and mouth disease in the United Kingdom that last 221 days. During this period, over 6 million cows, pigs and sheep were butchered and burned. Agriculture sector suffered significant losses as just direct losses were almost 2,4 billion pounds. Foot and mouth disease led also to banning all exports of meat, milk and livestock products from United Kingdom by the European Commission, the United States, South Korea and Ireland. Impacts of this disease extended also outside of the agricultural sector as for example British tourism suffered when quantity of tourists decreased. According to Kato & Charoenrat (2018), survey made in Thailand between 2002-2012 points out that almost 50 % of questioned SMEs had suffered business losses because supply chain disruptions that express their commonness in today's global business environment.

Measuring or quantifying economic impacts of supply chain disruptions is challenging because there are multiple different types of disruptions as presented in previous chapters. Wu, Blackhurst & O'grady (2007) have designed a Disruption Analysis Network model to define how disruptions expand within supply chains and calculate their impacts. Based on this model, it can be noticed that if the disruption event is handled quickly, the lead-time of the order increases five days without increasing costs. In addition, utilizing outsourcing may shorten the increase of delay,

but at the same time it increases costs by around 15 dollars per unit if delay time is reduced to three days. Thus, companies face trade-offs between costs and lead-times. It has been notified that supply chain disruptions have both short-term and long-term financial impacts (Tang 2006a). Financial impact may vary from 100 dollars to 50 million dollars per day according to Mitroff & Alpaslan (2003). Hendricks & Singhal (2003) examine disruption costs from the perspective of shareholders. They noticed that if company announces publicly about supply chain disruption which may result in potential production or shipping delays, it decreases stock price by around 10 percent. Hendricks & Singhal (2005) analyze also how supply chain disruptions effect on long-term stock price performance. It has been noted that disruption causes -40 percent decrease in stock return on average in a time period from one year before until two years after the announcement date of disruption. In addition, Bode & Wagner (2015) point out that supply chain disruptions may cause significant long- and short-term losses in shareholder value, sales and reputation of company as well as damage relationship between customers and suppliers.

When supply chain disruption occurs, it is extremely important that companies learn from these experiences (Jüttner & Maklan 2011; Zsidisin et al. 2005). Bode & Macdonald (2017) argue that the impact of supply chain disruption depends on company's readiness, supplier dependence and supply chain complexity. Devergas (1999) identifies three potential areas of business impacts. These are business interruption, revenue loss and embarrassment. Business interruptions, for example disruption of production, may have impacts almost immediately as they disrupt all production and delivery obligations. Also, Ellis et al. (2010) argue that supply chain disruptions may have a negative effect on productivity and capacity utilization of the buying company and weaken company's ability to satisfy its customers. Also, revenue loss may occur immediately after disruption if customers sense that the company is not able to continue normal production. It is typical that raw material, finished goods and distribution channel will not suffice to respond to customer orders. Embarrassment in turn, bases on an assumption that every company has a certain amount of visibility within its market area which it must secure. If company fails to meet its commitments consequently, it might lose its reliability since customers are not companionate to problems. (Devergas 1999)

In addition, when considering impacts of supply chain disruptions, it important to examine how risks and consequences can be shared between buying company and suppliers. Harland et al. (2003) state that companies should use risk-sharing contracts for handling supply chain risks. Wakolbinger & Cruz (2011) emphasize the role of contract negotiations in sharing costs and profits between the buying company and suppliers. In ideal situation, profits would be shared fairly between supply chain parties, but it is not rare that some members obtain most of benefits. Information sharing bases on same idea but there can be seen also cases where for example manufacturers have obtained more benefits from information sharing (Lee et al. 2000). According to Inderfurth & Clemens (2014), penalty and reward elements for supplier are typical risk sharing characteristics and the type of contract defines which part takes the higher risk. Penalty contracts transfers risk to supplier because if it is not able to produce ordered quantity, the buying company is justified to demand penalty fee for under-delivery. However, contracts can be used in favor of supplier if over-production risk sharing contract is utilized because in this case buying company accepts supplier's agreed production output even though demand would be lower (Gurnani & Gerchak 2007; Yan et al. 2010) Xia et al. (2011) presents two approaches for contracts between buying company and supplier. First one, option contract with guaranteed supply, sets major risk for supplier because the buying company purchases guaranteed delivery of products with premium price. Second contract, firm order contract, is classic approach where the buying company has higher risk, but the price is lower at the same time. According to Wang et al. (2009), it is typical that companies are using alternative suppliers for avoiding single source situation.

According to Harland et al. (2003) success of supply chains bases on long-term commitment of the supply chain members and ability to share benefits and risks between them especially in case of joint product design, process design and supply chain innovation. Wakolbinger & Cruz (2011) emphasize the role of contracts when considering the impacts of supply chain disruptions. They are used to specify who needs to incur the costs of supply chain disruptions. Hence, the main idea behind these contracts is sharing risks and costs of supply chain disruptions between buying company and suppliers. In addition of risk-sharing contracts, supply chain

wide visibility of disruption risks and information sharing have important role in supply chain risk management. As an example, information sharing can be applied as joint problem solving with supply chain partners and best practices can implemented through the whole supply chain for managing disruption risks more efficiently. (Kleindorfer & Saad 2005) Furthermore, Fawcett et al. (2000) state that if company is able to utilize this information in the planning process, it has critical role in selecting and developing possible capabilities to deal with disruptions.

4. Research design

This chapter defines the methodological choices and the execution of this research study. First subchapter will briefly present selected research methods whereas second subchapter focuses on data collection and analyzing methods. Third subchapter will introduce the case company and finally the reliability and validity aspects will be discussed.

Empirical part of this research begins from this chapter. Following chapters will present empirical findings of the research and compare them with earlier literature for providing answers to the research questions. First, the qualitative findings are presented where the focus is especially on supply chain disruption events, their financial impacts and how these impacts can be controlled as well as developing business impact analysis model. Main findings from qualitative interviews are presented later in table 13 in the chapter 6.1. The second part in turn, presents the development process of calculation model with examples and benefits of implementing new model.

4.1. Research methodology

This research utilizes mixed research methods. According to Fidel (2008) mixed methods research combines qualitative and quantitative methods that can be mixed in multiple ways for different purposes. Mixed methods ensure the quality of the research by decreasing biases, limitations and weaknesses that utilization of single research method may cause. In addition, Saunders, Lewis & Thornhill (2009) note that possibilities to answer to the research questions are better if multiple methods are used.

Mixed methods are chosen for this research because it combines qualitative semi-structured interviews and quantitative use of data from the case company. In mixed methods research, qualitative and quantitative methods are combined in concurrent

or sequential forms. Concurrent mixed methods research uses qualitative and quantitative methods separately within a single phase of data collection and analysis. This enables more extensive and more comprehensive response to research question than if only one method would have used. Whereas sequential mixed method research, involves more than one phase of data collection as the use of one method will follow with another in order to expand or clarify the original set of findings. (Saunders et al. 2009) The roles of these methods are divided in a way that qualitative research defines the background and objectives for quantitative research which focuses on developing a calculation model for analyzing financial impacts of supply chain disruptions.

This research is executed as a single case study. Case study can be defined as an empirical method to investigate a contemporary phenomenon in real-life context with multiple source of evidence (Halinen & Tornroos 2005). According to Stake (1995) case study provides a comprehensive outlook on the method if complex object is studied in a specific context. It is typical for case study that multiple data collection methods such as interviews, observation and documentary analysis are used for achieving rich understanding of the studied subject and its context (Saunders et al 2009). The case study combined with interviews allows deeper discussion about background and fundamental reasons behind the topic. This enables gathering rich empirical data and thus gaining deep understanding on research problem. (Kähkönen 2011)

4.2 Data collection

The empirical part of this research utilizes data from two sources which are interviews and numerical data provided by the case company. The qualitative data is collected by utilizing semi-structured interview form. Semi-structured interview is chosen since as Saunders et al. (2009) note it bases on specific themes and questions, but it is flexible and allows varying between different cases. In addition, semi-structured interview is a flexible data collection form as it includes a possibility to present additional questions (Chu & Ke 2017). Interview questions were defined

in advance for connecting them with research questions and theoretical background of the study. Interview question form is presented in Appendix 1.

Interviewees were chosen based on their knowledge and experience related to sourcing, supply chains and risk management. Each of those interviewees have worked multiple years in the case company and they are working in different departments for acquiring comprehensive empirical data over supply chain disruptions and their impacts on the case company. 9 case company professionals were contacted and all of them were interviewed. Their roles and experience in current roles are presented in table 8. Thus, the response rate was 100%. The interviews were executed as face-to-face sessions or Skype calls and all of them were recorded for increasing the reliability of analyzing the results. In addition, 7 interviews were translated for enabling the use of quotes in the analysis of results. The empirical data was collected during October-November 2018 and the interview length warried from 39 minutes to 130 minutes. As interviewees have different backgrounds, experiences and different point of views towards supply chain of the case company, interviews provided extensive and versatile empirical data for analysis.

Table 8 Interviewees

Role	**Experience at role**	**Duration (min)**
Sourcing Risk Manager	1,5 years	54
Unit Director	6 months	48
Unit Sourcing Manager	1 year	66
Sales and Operation Planning Director	4 years	80
Legal Counsel	1 year	70
Area Director	4 years	39
Risk Manager	5 years	90
Delivery Chain Program Director	1 year	130
Sourcing Controlling Director	7 years	52

The aim of the interviews was to get overview about current level of supply chain risk management in the case company and identify most critical disruptions types and their impacts. The interviews were used also as a background for designing business impact calculation model.

Furthermore, secondary data is collected from the case company's systems for supporting interview results. According to Saunders et al. (2009) it is typical to use documentary secondary data if research study utilizes also primary data collection methods. This data may be in written form such as administrative and public records, minutes from meetings and journals or presented in an alternative form.

In this research, second research method consists of developing a calculation model for the case company based on data from company's systems. Because calculation model aims for estimating global business impact of supply chain disruptions, feedback from most important stakeholders will be utilized. The model will be developed as a pilot project on one factory before global implementation. Hence, this method includes user perspective for offering functional tool for analyzing supplier risks.

4.3 Data analysis

This research utilizes content analysis as an analyzing method. The units in content analysis may be words, sentences, paragraphs or themes (Tesch 1992). According to Krippendorff (2004) content analysis focuses on making valid implications from chosen research material. In this research, analyzed content are themes which were discussed in the interviews. Content analysis is clear choice for the analyzing method in this research since there can be identified 4 main themes: 1) supply chain risk management, 2) information sharing, 3) supply chain disruptions and 4) business impact analysis. All of these have also sub-themes which will be further analyzed. The categorization of main themes has been made based on the objectives and research questions.

Analysis of numerical secondary data for the calculation model is done with Excel and is grounded on requirements set by the case company. The calculation model is based on combining forecast data of different units with suppliers and financial data. Because data is collected from multiple excel files, Excel is good tool for this purpose as it enables combining data from different files simply as well as sharing model to users. Excel based model is also easy to use and requires only brief introduction. Furthermore, Excel can be used to visually present connections between suppliers and end products including the possibility to illustrate material flow between different units of the case company.

4.4 Reliability and validity

Reliability and validity of the research are aspects that must be considered. Reliability is related to the consistency of the results if the study is performed in different settings as time or environment changes whereas validity present if the results of the research represent what they are defined to be (Silverman 2011). Reliability of qualitative research depends strongly on the researcher and for example planning of interviews and questions as well as transcribing the interviews have a critical role in the reliability of the study as Hirsjärvi & Hurme (2001, 184-187) states. According to Yin (2003), the most common method to analyze the quality of case studies are construct validity, external validity, internal validity and reliability.

Construct validity is related to selecting the specific issues to be studied and defining specific measures to reflect with those. There are three ways to establish construct validity: 1) use of multiple evidence, 2) establishing a chain of evidence and 3) having key informants review a draft of case study report. (Yin 2003) This research utilizes semi-structured interviews and systems of the case company for collecting data and the results will be documented for creating a comprehensive general view over the researched topic. Thus, it can be stated that the construct validity is on acceptable level.

External validity refers to the generalization of the results whereas internal validity focuses on analyzing if a specific event is leading to another (Yin 2003). In this research, the focus is strictly on specific case study which sets some limitations for generalizing the results. Nevertheless, supply chain risk management and supply chain disruptions are studied on universal level and if certain requirements are fulfilled the calculation model may be implemented also to different environments. Internal validity is applicable as well since the focus is on examining what are the consequences of supply chain disruptions and qualitative research leads to quantitative development of the calculation model.

In this research, data is collected via 9 semi-structured interviews from respondents with various backgrounds for improving the reliability. Because interviewees work at different levels of the organization, this number of interviews give extensive picture over the role of supply chain risk management and impacts of supply chain disruptions for the case company. In addition, reliability is improved by using two data collection techniques. Saunders et al (2009) point out that triangulation considers different sides of studied object for providing a complete understanding over the topic. The reliability of the research can be improved if the collected data is categorized (Yin 2003). For this reason, categorization based on 4 main themes have been made. Translation of interviews may have an impact on the reliability of the research, since the original meanings may be changed during translation. The second part of this research, developing a calculation model, is based on both interviews and number data from the case company. Interviews provide requirements and the scope for the model. As the model utilizes numerical data, there is no human error in values which increases the reliability of this part significantly.

4.5 Case company description

The case company has been founded in 1910 in Finland, is one of the global market leaders in its industry. The company operates in over 60 countries and serves more than 450 000 customers. As a multinational company it has seven production sites,

eight R&D centers and also a worldwide network of authorized distributors. As being a large company, the organization structure consists of manufacturing units, supply units, country sales units and corporate support functions.

This research is done for global sourcing unit and the focus is on the entire supply chain inside the company and supplier level. Thus, all manufacturing units and supply units are in the scope of this research. The case company has started to invest more on supply risk management during recent years. There has been made internal business impact analysis already earlier but that does not include supplier perspective. However, this offers a starting point for this research even though earlier analysis cannot be utilized as a ground to be built on.

The product offering of the case company varies between different supply units based on demand of different market areas. For this reason, the analysis must take into account characteristics of different units for building a reliable and general model. This model for analyzing business impact of supply chain disruptions is planned to be supporting tool for finding critical suppliers with high business impact and comparing different scenarios of changes in suppliers' capacity.

5. Empirical findings

This chapter presents the findings and results based on primary data collected from interviews and secondary data from the case company's database. The main objective of this research is to develop calculation model for business impact of supply chain disruptions. Furthermore, this study aims for analyzing what kind of costs supply chain disruptions cause and how the possible impact can be shared between supply chain members. First part of this chapter focuses on qualitative results. The other part in turn, presents results of quantitative analysis that consists of identifying method to estimate the impacts of supply chain disruptions.

5.1. Supply chain disruptions in the strategy

Several interviewees considered that corporate strategy or sub-strategy closest to them pay attention on supply chain risks. Avoiding single source situations has important role in the strategy as the share of the case company's purchases from suppliers' revenue is limited. Hence, it is required that at least one alternative supplier is used if available. According to Unit Sourcing Manager, supplier risk is one sourcing's KPI metrics and thus each unit focuses on analyzing risks related to its suppliers.

"Category and unit continuity planning are essential parts of supplier risk management."
Sourcing Risk Manager

There exist business continuity plans for suppliers and the units of the case company that are updated every six months. Unit's business continuity plans are used for mapping critical suppliers and identifying possible single or sole source situations. Suppliers' business continuity plans in turn, focus on recognizing possible risk events and how their impacts could be mitigated. It was pointed out that the company tries to be as close to customers as possible and for this reason

it has units around the world and each unit has both local and foreign suppliers. This enables short delivery distances and thus, risk of disruptions during delivery to customers is lower. Multiple interviewee stated that there has been seen significant development during last two years and supply risk management for mitigating supply chain risks is ongoing. However, it was recognized that problems can be really deep in the supply network that makes it difficult to understand the root cause.

"It is important to know if some materials have single source situations and what are risks of disruptions for those."
Sales and Operations Planning Director

One highlighted theme was identifying, managing and evaluating supply chain risks. It was noted in the interviews that supply line sourcing has an important role in this as they are working daily with suppliers. The case company is utilizing multiple methods for measuring and identifying supply chain risks. There exist for example product and supplier-based risk lists in categories' continuity plans and location risk mapping which is impacting on supplier selection. Supplier risks were pointed out to have an impact on supplier selection as Unit Sourcing Manager and Unit Director both emphasized that there must be decided how many suppliers are used per component type and what is their status for example price leader versus reliable quality supplier. However, utilizing more than one supplier requires big total volume that it could be shared reasonably for making the case company attractive customer.

"When selecting new suppliers, supplier evaluation has important role – recognizing risks through audits and interviews can be seen as current trend."
Unit Director

When considering risk identification, it was notified that this should take place on component level already in the beginning of planning new products for ensuring that there will not be single source situations in production. For example, Risk Manager stated that the case company has dual source guideline which means that when designing new components, there must exist at least two suppliers which are able to supply this component for avoiding dependency on single source suppliers.

Hence, identifying supplier risks require co-operation between different functions, for example R&D and sourcing, since at this moment metrics or tools do not recognize risks. However, the main challenge is that risks are identified mainly on first tier suppliers even though the possible problem may be even on fifth tier if it delivers to multiple upstream suppliers. In addition, the focus is mainly on bigger suppliers even though small suppliers that have lower level of risk management may cause even worse problems.

"Second source should be defined when new product is ramped up and sources for all components must be mapped."
Unit Sourcing Director

It was notified that supply chain risks must be considered already before making contract with new supplier. According to Legal Counsel, annual spend should be estimated so that appropriate contract template can be selected. Unit Sourcing Manager argued that supplier validation should cover also supplier risks and effective risk management would require more resources and reducing the size of supplier base because at this moment it is not possible to intervene on all supplier risks. In addition, she stated that if suppliers' performance is not on required level, the case company continues business affair too long and just recently the use of second source suppliers has actively increased. In addition, it was seen that lack of resources is a problem that prevents utilizing second source actively as it is impossible to manage efficiently bigger number of suppliers because of too large supplier base.

According to all interviewees, supply chain risk management has developed significantly since the case company has started to focus more on supplier risks. Even though its importance has been notified by the top management, all aspects must be still improved. Sourcing Risk Manager presented suppliers' financial security as an example. Whereas Unit Manager emphasized differences between China and Europe as in China supply risks have been reduced significantly by using more suppliers which locate close to the factory whereas in Europe there are bigger challenges as low-cost country suppliers are used increasingly more that increases

distance between the case company's factories and suppliers. He stated that Europe is divided between north and south, but suppliers are delivering across to both areas without proper coordination. Implementing smart way to manage low-cost country sourcing for finding balance between cost and risk impacts by mapping processes and recognizing efficient functions were seen also to be important since possible costs may exceed achieved savings explicitly. Thus, there would be need for continental strategy for managing supplier base more effectively and optimizing delivery times which have a critical role in the case company's business.

"Financial problems are growing problem in Europe and supplier field is partly disappearing – as a consequence use of low-cost country suppliers increases."
Unit Director

It was highlighted that if basic risks are under control, reacting on surprising events become easier. Interviewees notified also challenges that need to be considered. One of the biggest challenges is weak visibility into suppliers and especially lower tier suppliers. Another bigger challenge is product harmonization as there are partly different product selections for example in Europe and China which sets limits for risk sharing. In addition, the case company was pointed to have multiple single source situations which may cause remarkable business impacts if risks realize. It was seen that currently there does not exist tools or processes that would support supplier risk management properly as Unit Sourcing Manager argued. Few respondents regarded that another main challenge with supplier risk management is that risks are identified mainly for first tier supplier even though single source supplier may be on second or third tier. However, interviewees had positive attitude towards future development of supply chain risk management since organization supports development. Risk management has already become more systemized and all supply units have implanted business continuity planning into their strategy. For future development, interviewees proposed that business continuity plans could be updated even quarterly, and the focus should be on developing proactivity and better recognizing of disruption events. In addition, it was pointed out that the case company could harmonize its activities between different units by decreasing

variance in the product portfolio so that in supply chain disruption situations, impacts could be reduced.

"Utilizing design and product portfolio for reducing product variance so that own factories could make same products for increasing flexibility – at this moment factories are rather specialized."
Risk Manager

5.2. Information sharing

The importance of information sharing both inside the case company and with suppliers was noted to have an important role related to supply chain disruptions. It was seen that category management is responsible for sharing information relating to supply chain risks and disruptions inside the company. Interviewees hoped that they would get information about potential risks and what might be their impact. However, Program Director argues that when sharing information, they must be extremely careful when deciding what will be shared and to who so that it will not cause panic inside the organization. Legal Counsel in turn, regarded that supply chain disruptions are escalated to legal only when risks have realized, and orders cannot be delivered to customers.

There was seen also disagreements between respondents as few of them told that there are channels for information sharing are on good level and relevant persons have access to it. Monthly megawebcast where actual issues are going through was mentioned as an example. Rest of interviewees stated that sharing information is not controlled and every unit must take care of its own problems even though suppliers that are responsible for disruptions may be delivering to multiple units. It was seen that information is shared typically word to mouth instead of coordinated newsletters or webcasts.

"Sharing information and utilizing mass of data are not strengths of the company."
Sourcing Controlling Director

When it came to the type of information that would be useful to share interviewees highlighted what kind of disruptions have appeared and how they could affect to the current situation. It was pointed out that even though aim is to be open and transparent, sharing information without proper preparation may have a negative impact as rumors start to spread quickly if it cannot be told when disruption will be over what are impacts of recovery. In addition, the type of disruption effect on the requirements of shared information. Many disruptions are building over time before impact and in these cases, it would be important to get a warning of increased risk compared to surprising disruption when it is not possible to act proactively. Legal Counsel emphasized that it would be good to know this before starting contract negotiations with suppliers so that they can consider possible risks in contracts. In addition, supplier's financial situation is important to be shared since if supplier's responsibility is limited to one million euros even though already 50 000 euros would be enough if supplier does not get compensations from insurance, it would be useless to have this kind of clauses in the contract.

"Objective is to know impact of disruption, when it will be over and how recovery impacts before sharing information since rumors start to spread out quickly."
Program Director

When considering the way how information related to supply chain disruption is shared to internal stakeholders and is available in the organization, there was seen disagreements between interviewees. Few of them said that this changes according to situation and type of disruption but nevertheless sharing information is not a challenge. Others in turn stated that there is lot of improving ahead and if one is asking, he might get information, but nothing is shared actively. It was pointed out that legal unit is not always aware of suppliers' risk profile which causes challenges to contract negotiations as they are focusing only on suppliers' comments to the case company's contract template instead of considering related risks. The challenge with information sharing was presented also between corporation level and supply unit as on supply unit level were not satisfied with current situation whereas corporate level believe that information is shared efficiently to relevant stakeholders. However, there exist global instructions that should be followed if risk

is on, but few interviewees hoped that information would be shared more coordinated also proactively.

"Before contract negotiations, it would be good to share what kind of disruptions similar suppliers have faced earlier and their financial situation for including needed clauses such as supplier's insurance."
Legal Counsel

It was noted in the interviews that almost all respondents are utilizing information relating to supplier and supply chain risks regularly. This information is used especially for sharing it to projects so that they would have time to prepare for example by ramping-up second source, reviewing performance and communication with insurance companies for getting prices on right level. Interviews revealed also internal problems concerning to supply chain risks because frontline units are not completely relying on supply units' capability to deliver all materials to customers on time. For this reason, there are little buffer in their forecasts which in turn makes it more difficult for supply units to plan their demand and communication with suppliers. This emphasizes the role of trust between frontline units and supply units and almost all interviewees noted that reliability of forecasts must be improved.

There were seen disagreements relating to how supplier risk information and its quality is collected. Some of the interviewees regarded that there are not any instructions how information about supplier risks should be collected. Instead, case by case information can be found from personal computers. They stated that currently information covers only small part of supplier base. In theory, information should be collected from all suppliers but because is unrealistic, there should be decided how to choose and prioritize which are most critical suppliers. Program Director in turn, argued that information is collected broadly covering all kinds of risks. It was pointed out that risk audits where information relating to operative risks, natural hazards, financial and cyber risks are made for the most critical suppliers with the insurance company.

"Currently not widely enough – focus on big suppliers even though small ones may cause even more several problems."

Sourcing Controlling Director

When considering the quality of information, some of respondents argued that suppliers are a bit too optimistic and for this reason they must be careful when using this information. Sourcing Controlling Director points out that for example risk scorecards are based on surveys which are sent to suppliers but since many of them are privately held companies, there is not possibility to double check their answers truthfulness as financial statements are not public. The main challenge is that suppliers are estimating their situation on different ways that makes it difficult to compare them. All of interviewees regarded that the quality of information must be improved as it bases too much on subjective opinions at this moment. Suppliers are also estimating their situations on different ways which make it more challenging to compare suppliers with each other. However, it was seen that the quality of information is on good level and instead Risk Manager regarded that the biggest problem is how to react on existing information.

"Current data is of good quality, but it is in small pieces."

Sourcing Risk Manager

Table 9 Summary of information sharing

Information sharing inside the case company	What kind of information should be shared	Quality and reliability of information
- Channels are on good level and relevant stakeholders have access - Every unit responsible for own problems – other units should be informed if common problems - Information is shared regularly - Sharing information and using mass of date are not strengths of the company	- What kind of disruptions have appeared and risk index based on them - How disruptions affect and recovery plan - What disruptions similar suppliers have faced earlier - Information should be shared proactively	- Suppliers are often too optimistic - Quality must be improved - Good quality, but in small pieces - Suppliers are using different methods for estimating their situations - Biggest problem is how to react, not the quality

Table 9 presents a summary of central notifications relating to information sharing that came up in interviews. It can be seen that there exist both similarities and disagreements in the answers of interviewees. Disagreements are related to how information is shared inside the company and the quality of information about supply chain disruptions. When it comes to the type of information that should be shared, interviewees agreed that it would be important to know what possible impacts of disruption are, what recovery actions are and that information should be shared early enough.

5.3. Impacts of supply chain disruptions

Figure 10 presents most typical risk events which came up in the interviews. Fire in supplier's factory was considered as the most common risk event and the case company has recent experience from situation where partly single source supplier's plant is destroyed in fire. For example, Unit Sourcing Manager pointed out how this disruption had potential to cause significant delays but partial second source supplier was able to increase their volume and implement multiple new products that reduced impact of disruption substantially. Other typical risk events that realize in the supply chain regularly are natural hazards such as earthquakes, floods and hurricanes, material and capacity issues as well as ERP changes and cyber-attacks. Program director described that the company is surprisingly vulnerable for disruptions, partly because of internal silos where information does not move properly and transparency in delivery chain would improve the situation. In addition, since the case company operates globally, it must take into account political environment and local laws. Unit Director gave an example from China where for example chemicals suppliers' do not always comply with environmental law which may lead to shut down of entire factories in worst case.

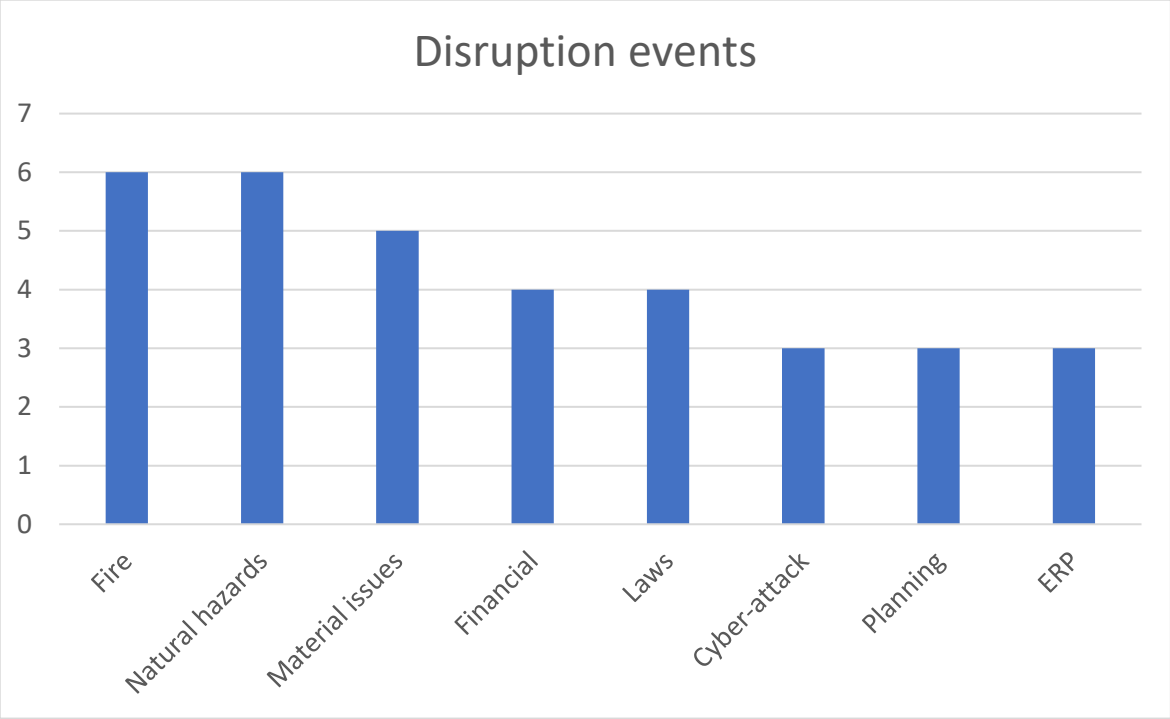

Figure 10 Disruption events

According to few interviewees, financial risks have become more common as well as capacity risks which relate directly to the accuracy of the case company's forecasts. Sourcing Manager pointed out that also suppliers' own risk management has a significant role because ERP or any other changes in supplier may cause serious problems especially if supplier does not have existing business continuity plans. It is most typical that disruption takes place in lower tier suppliers and for this reason the ground reason may be seen too late for proactive activities. In addition, three respondents named cyber-risks as growing problem and the most significant single risk in the future and also the case company has been a target of cyber-attacks during last year. It was pointed out that follow up of suppliers has crucial role in identifying possible disruptions before they even realize. This in turn enables setting up mitigation activities proactively and thus reducing the severity of possible impact. Sourcing Controlling Director stated that most of supply chains disruptions could have been prepared for if there were early indicators in place.

"The company is surprisingly vulnerable for disruptions – partly because of internal silos where information does not move. Transparency in delivery chain would improve the situation."
Sourcing Controlling Director

Interviews pointed out that there can be seen clear geographical differences. Asia is the most important area because of highest volume. Hence, supplier base must be reliable enough for securing manufacturing. In addition, operations are more flexible and dynamic there, and suppliers are more willing to develop. In Europe in turn, business is not that attractive and supplier base is smaller. Attractiveness of the business is also related to the financial risks and it was noted in the interviews that they were seen as a growing problem especially in Europe. In the United States in turn, there can be seen high number of disruptions even though volume is rather small. Long lead times were seen to be the main reason for this as Sales an Operations Planning Director pointed out. When it comes to natural hazards and political risks, it was regarded that these kinds of risks can be mapped, but they are still causing significant disruptions.

The costs of supply chain disruptions were seen to be comprised mainly of expediting costs, loss of sales, use of more expensive replacing supplier and delay penalties. Expediting costs are the most common of these as even small delays in suppliers' deliveries may force to expedite transportation or use overtime work. It was seen that implementation of new suppliers or using back-up supplier cost usually much more and requires more resources from the case company's own personnel and their working time. In addition, if supplier starts to deliver new component, its quality may vary significantly especially in the beginning. In addition, if the case company is not able to deliver products on time, it may result in weaken brand image. Loss of sales can be seen as an indirect impact of this if inability to deliver products on time leads to loss of future business with customers. Also, delay penalties are related to this since if supply chain fails in expediting, customers may demand these if the case company is not able to deliver products according to the contract. Interviewees told that these are quite rare, as Legal Counsel presented, delay penalties for the case company defined in sales contracts are higher than

penalties for suppliers. However, the cost of disruption depends on its type and there can be seen significant differences between catastrophes and smaller incidents. Supply chain disruptions have also indirect costs such as loss of future sales because of negative customer experience. Unit Director and Risk Manager pointed out interesting notification that excellent ability to recover from disruption can create also market share if customers see that the company is capable of handling risks can consider it to be more reliable than competitors. Conversely, negative customer experience may take customers and loss of future profit can be seen as indirect impact.

According to Sourcing Risk Manager, supply chain disruptions are causing only small costs because recovery actions are on good level. This is supported by Sales & Operations Planning Director as she pointed out that usually customer does not even notice disruption since the case company controls the major part of supply chain from manufacturing until installation to customer. Hence, it has time to expedite the process for following agreed schedule.

"Even small disruptions in supply chain may can cause one day delay in customer delivery."
Area Director

Interviews pointed out that there have been multiple mitigating actions against supply chain disruptions. Business continuity planning has been developed globally more professional which in turn helps know suppliers better. In addition, focus is especially on analyzing single source material situations as Sourcing Risk Manager argued. Unit Sourcing Manager in turn, describes that the case company has second source plan which aims that all materials or entireties would have second source which would have same price level and available capacity. However, because the possibility of supply chain disruptions is always existing, they have also been notified in budgeting and money is reserved for unexpected costs since majority of impacts appear as negative surprises such as speed up and expedite costs. All interviewees emphasized that profitability of products is planned, and disruption costs are straining it directly. For this reason, it is extremely important to

consider possible disruptions beforehand and make both recovery and mitigation actions.

"If costs can be cut of, all is seen under the bottom line."
Unit Director

The role of purchasing contracts in supply chain risk management was also emphasized as they define how costs are shared between parties. It was pointed out in the interviews that contracts are used for limiting possible costs for the case company. Contract defines responsibilities between parties, and it is required that supplier must prove that they will have sufficient insurances in force to cover the potential risks. In addition, when considering contracts, the case company must ensure under which country's laws contracts are made because they may differ significantly from each other. Knowing foreign laws require also knowledge from personnel which may cause problems if commonly used laws are not used. Legal Counsel told that in theory, compensations should be demanded from suppliers if disruption is their fault. The case company would have a possibility to demand compensations for loss of future sales if can be shown what the reason is. However, usually case company's own insurance is utilized for applying compensations, but there are impacts such as reputation impact which are hard to cover against. Few respondents pointed out that customers are demanding compensations easier than the case company demands from its suppliers and significant penalties were payed to customers. Majority of interviewees regarded that even though contracts and insurances can be used to limit disruption costs, the case company pays always most because it carries the responsibility of efficiency of the entire supply chain which means that it does not put the blame on single suppliers publicly.

"No matter what happens, (the case company) always pays most because it has chosen to take the full responsibility."
Program Director

It was pointed out that information relating to additional costs of supply chain disruptions is not collected systematically at this moment. Few interviewees argued

that expediting costs such as transportation and overtime work are easy to collect but many additional costs can be seen only after the project has been closed. In bigger cases, all costs should be collected and sharing of costs is negotiated with supplier but there are not any global instructions for this. Instead, it is important to understand what root causes behind disruptions are, but as Program Director stated, compensations will never cover the whole damage. It was pointed out by interviewees that cost information is not utilized well enough as it is mainly used for applying compensations from insurance company. Few of them emphasized that it would be important to hear more root cause analyzes and cost information should help to understand better which most critical suppliers and materials are.

"Insurance compensations are applied only in case of biggest disruptions because collecting cost information is so arduous – big part must be collected manually."
Unit Sourcing Director

The ultimate direct consequence of supply chain disruption is penalty cost if customer delivery delays. These sanctions may be several times higher than to the value of the case company's products and thus they have significant impact on profitability if customers decide to claim those. Nevertheless, penalties are rare since the case company usually manages to expedite the process and avoids delay seen by the customer. It was pointed out that the case company may demand penalties from suppliers and in some cases, it is also possible to demand other additional costs from suppliers if this is not ruled out on contract. However, it is typical that instead of claiming penalties, they are used as additional leverage in contract negotiations for getting better price for next contract period.

"It depends on contracts if disruption costs can be targeted to suppliers."
Risk Manager

5.4. Business impact analysis of supply chain disruptions

When it comes to the business impact analysis, interviewees presented multiple different perspectives over the question about developing new calculation model. Central notifications are collected to the table 10 below. Unit Director regarded that it would be useful to consider what kind of suppliers are included into the model based on their risk level. It would be good if the model would use product level information and the impact could be targeted to different platforms. It was seen to be important that material shortages and product level should be linked to each other for understanding how separate suppliers can be linked to the final products. In addition, it was emphasized that model should be simple and easy to use for analyzing which suppliers need most resources for disruption mitigation activities or implementing second source for reducing the risk. Unit Sourcing Director pointed out that if the business impact of supply chain disruption could be estimated for supplier, it would help in negotiations with supplier as possible disruption costs could be presented.

Table 10 Summary of business impact analysis

The level where BIA should be made	How BIA could be utilized in business continuity planning
- Suppliers should be chosen based on their risk level - Combining factories with product platforms - Frontlines are closest to customers - The model should be scalable - Suppliers, factories and supply units should be at least included	- Helps to find most critical suppliers to which should be used more resources - Provides the profit loss caused by suppliers - Information should be shared to sourcing for considering implementation of second source - Tool for prioritizing - Helps in unit level planning

On the other hand, few of respondents regarded that the calculation model should start from frontline units as they are closest to the customers and have best perception over what impact for customers would be. In addition, the calculation model should include supply units and suppliers for analyzing the general view. All interviewees agreed that the model should include at least most critical suppliers,

the case company's own factories and supply units. The main difference was if the calculation model should include separate frontline units or should they be analyzed based on area level. Nevertheless, the objective should be finding a scalable model that could be enlarged over the course of time.

When it came to calculation of the business impact, interviewees had two different opinions how to calculate the disruption impact. First one was calculation based on the costs that disruption causes to frontline units, supply units and suppliers. However, the challenge was that this information was not systematically collected that makes it difficult to generalize costs relating to different disruption events. Another presented idea was calculating the business impact as a loss of profit if disruption realizes. This was seen simpler and straightforward method as the impact can be calculated based on products' profit margins and supply units' forecasts. Hence, the second method was chosen to be utilized as the starting point in the development of the calculation model. In addition, BIA should be made on global level because thus the total impact is notified. Risk Manager gave an example that a single disruption may cause impact of two million euros to single unit but the impact to rest of organization is 30 million euros. Thus, the importance of global level is justifiable.

Risk Manager presented existing business impact model that could be utilized as a guideline for new calculation model, which would include also suppliers. This was also built on profit values and volume forecasts, but its focus is only on the internal units of the case company and profitability values were used on overall level. New BIA calculation model is aiming to go further upstream to the first-tier suppliers and when considering the development process, it was notified that the analysis should be based on more detailed information of product structures. As an example, first a way to combine factories' components with product platforms and profit margin should be calculated for each platform separately.

It was highlighted that business impact analysis is important for the case company as it could be utilized for identifying most critical suppliers. It would help to prioritize mitigation actions or alternative supplier identification. Since BIA presents monetary

impact, it would provoke both the case company and its suppliers to make and validate BCPs regularly. It was seen be important that also suppliers update their business continuity plans and understand the monetary benefits of those, especially what is monetary loss and are their insurances sufficient if something happens. Furthermore, if costs of possible disruption impact can be shown to suppliers, it would motivate them more to invest on BCP than just describing risk level verbally. Sales & Operations Planning Manager and Legal Counsel regarded that BIA could be used for following if certain risks are repeating which in turn helps to understand what kind of risks are related to each supplier.

5.5 Developing the business impact calculation model

The aim of this chapter is to describe the development process and required inputs of the business impact calculation model. The objective of new calculation model is to estimate the profit loss for the case company caused by supply chain disruptions. This model can be seen as a following step for existing business impact model as this presents the most critical suppliers for which more efficient mitigation activities should be considered. The scope of the calculation model is global, and it covers all factories and supply units in several locations as well as first-tier suppliers.

5.5.1 Developing process

The development of the calculation model began with setting up the objectives and defining required input data. The objectives were defined together with Sourcing Risk Manager and based on these, required data was defined with Sales & Operations Planning team. The background research included examining existing data that could be utilized in model. The calculation model was created by Excel since data for the model was collected from multiple Excel files. All used data was retrieved from the case company’s databases. Most of files were already existing but suppliers’ purchasing shares were built for the purpose of this model. It was

decided that the model includes most critical suppliers, case company's factories and supply units. It was decided that frontline units and area level are not considered because profit margin per product can be defined on supply unit level. The development process includes eight phases and they are presented in figure 11.

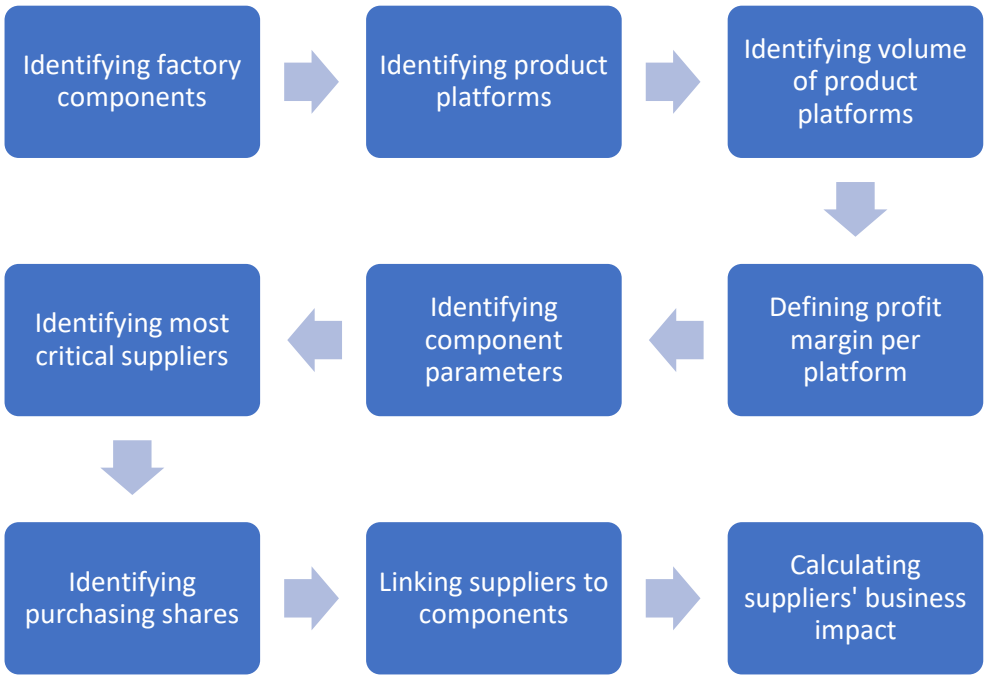

Figure 11 Development process of the business impact calculation model

After the existing data was analyzed, the first phases of development process were identifying components that case company's factory are making and final products that supply units are sending forward to frontline units. When these component and platform types were recognized, development process continued with defining yearly volume for each platform under each supply units. Next phase was examining profit margin for each platform as the business impact is calculated based on volume forecasts and profit margins. These values form the core data for the model that will be linked to suppliers based on component parameters and suppliers' purchasing shares.

Volume forecasts for factories are calculated based on component parameters which define which components are used in different product platforms. Suppliers in turn, can be linked to factory components and there exist purchase shares based

on which can be analyzed to which components suppliers are related to. The case company has also suppliers which deliver materials to distribution centers. For these suppliers it is possible to connect them directly to product platforms. The calculation model has a sheet where is defined an impact ratio based on which suppliers are related to different components in different factories and same kind of table has been made for distribution center suppliers. There is also calculated what is the share of components that each factory delivers to supply units since few components are manufactured in multiple factories and they are delivering also to same supply units.

The final phase of the model is defining the business impact for chosen suppliers. The calculation was made based on identified supplier – product platform combinations and suppliers' business impact were calculated for each supply units separately. The main challenge with developing a calculation model was the quality of data as different units has different methods to maintain data in their systems and collected data had to harmonize before calculation phase.

5.5.2 Presentation of the calculation model

The calculation model consists of three main parts which are presented in figure 12. First one includes case company's factories, components which they produce, supply units, product platforms and volume and profit margin for those. Second part consist of parameter information whereas in the third part suppliers purchasing shares are added to the calculation model.

Figure 12 Structure of the calculation model

In the first part, it is calculated what is the total share of each component's total volume that factories are manufacturing. In addition, volume forecasts and profit

margins belong to this part of the model. Example of these is presented in table 11 and it is assumed that all factories are delivering to two supply units.

Table 11 Forecast information

Factory			Supply unit			
Name	Type	Total share (C)	Name	Type	Volume (D)	Profit margin (E)
Factory 1	Component 1	60 %	Supply unit 1	Platform 1	1000	500 €
	Component 2	50 %		Platform 2	700	700 €
Factory 2	Component 2	50 %		Platform 3	500	200 €
	Component 3	70 %	Supply unit 2	Platform 1	600	350 €
Factory 3	Component 1	40 %		Platform 2	800	1000 €
	Component 3	30 %				

Second part focuses on combining factories' components with product platforms. This was made based on parameters which are used for providing forecasts for factories. Factory 1 is used as an example in table 12 for demonstrating this part. It can be seen that components 1 and 2 are substitutes for each other and parameter indicates distribution between those.

Table 12 Parameter information

Component	Platform	Supply unit	Parameter (B)
Component 1	Platform 1	Supply unit 1	70 %
	Platform 2		50 %
	Platform 3		60 %
	Platform 1	Supply unit 2	50 %
	Platform 2		80 %
Component 2	Platform 1	Supply unit 1	30 %
	Platform 2		50 %
	Platform 3		60 %
	Platform 1	Supply unit 2	50 %
	Platform 2		20 %

The third part in turn, focuses on combining suppliers with factories' components. This bases on defined purchase shares which depends on what kind of suppliers are chosen. Both single and sole source situations exist, but also situations where demand is shared equally between two suppliers. The example continues in table 13 which presents suppliers for factory 1. There are presented three suppliers which are delivering materials to both components that example factory manufactures. If suppliers are delivering multiple materials to same component, the highest purchase share defines the used ratio.

Table 13 Suppliers' purchase shares

Supplier	Component	Purchase share (A)
Supplier 1	Component 1	50 %
	Component 2	70 %
Supplier 2	Component 1	30 %
	Component 2	100 %
Supplier 3	Component 1	50 %
	Component 2	100 %

The business impact of supply chain disruption caused by single supplier is calculated based on values which are presented in tables above. The used basic formula is:

A = Purchase share, B = Parameter, C = Total share, D = Volume, E = Profit margin

*A*C*B*D*E = Business impact in year*.

This formula defines the business impact for single supplier – product platform combination under one supply unit. For getting the total impact, same calculation must be made for all related combinations and supply units. This method was chosen because, it provides more accurate information and highlights most critical combinations that may be further analyzed.

5.5.3 Benefits of the business impact calculation model

This chapter presents the main benefits of the new calculation model for business impact of supply chain disruptions. Because development process did not include common testing, benefits are collected through conversations with personnel of the case company and presenting functionalities of the calculation model. Feedback was received at the same time with development process and required adjustments were made according to it.

There exists already one business impact model for analyzing the business impact if the case company's own factories face disruption. The main difference between this and new model is that the new calculation model focuses to most critical suppliers and for this reason purchase shares and component parameters are considered. In the new calculation model, more exact profit margins are also used so that differences in profitability of different platforms can be taken into account.

The business impact is calculated based on yearly volume forecasts. Thus, if user of the model is interested in shorter disruption, it is possible to divide impact value with 12 for monthly impact or further with for example 4 for estimating impact of one week shut down. In addition, it is possible to adjust suppliers' purchase shares. These make model flexible for analyzing different supply chain disruption scenarios. The calculation offers a valuable tool for supplier management as it points out possible monetary impact of complete disruption which shut down supplier's production and this information can be as justification for investing on mitigation activities or implementing second supplier in single source situations.

The new calculation model enhances also the efficiency of communication as more accurate information relating to most critical suppliers can be shared to stakeholders. Furthermore, as risks are better recognized and required mitigation actions are executed, the business performance improves due to reduced impacts of single supply chain disruption events. Suppliers' business impact information may be utilized also when making category and continental sourcing plans and in product

development as sourcing, risk management and R&D may co-operate for ensuring that there exist adequate components suppliers and second source exists.

All in all, this research provides a tool which estimates financial impacts of supply chain disruptions for assisting decision making. The results are presented from the perspective of the case company that must be considered when reading results. However, this offered a possibility to examine the topic in the real-life corporate context which enabled building the calculation model on actual data for strengthening the reliability and utility in corporate environment.

6. Discussion

Supply chain disruptions can be seen as significant source of supply risk and the topic is actively examined by academics. Previous researches have mainly focused on analyzing supply chain disruptions on common level but there can be seen multiple researches relating to impacts of big well-known disruptions such as hurricane Katrina, Great East Japan earthquake and World Trade Center attack. For this reason, the goal of this study is to present the main impacts of supply chain which are typical the industry of the case company. Another main goal of this study was to develop a business impact calculation model for estimating the profit loss caused by disruptions in suppliers' factories. The research questions are as follows:

1. *What are the costs that upstream supply chain disruptions are causing in manufacturing industry?*
   - *1.1 What disruption events are seen most critical?*
   - *1.2 How disruptions costs can be mitigated?*
2. *How to calculate the business impact of upstream supply chain disruptions?*

Following chapters present answers to these research questions by discussing empirical findings against the theoretical background. First part of the analysis presents answer to first research question and its sub-questions. Second part in turn consist of analysis of business impact calculation model which provides answer to the second research question.

6.1 Impacts of upstream supply chain disruptions

This chapter aims to answer the qualitative part of this research. For doing so, view over the current state of supply chain risk management in the case company is presented based on interviews. Qualitative part of this research answers to first research question and its sub-questions.

The important role of supply chain risk management in reducing costs of supply chain disruptions was noticed both in the existing literature and the research study. Harland et al. (2003) and Wagner & Bode (2006) point out that globalization and increased use of outsourcing have made supply chains more complex and increased supply chain vulnerability. As a consequence, the number of supply chain disruptions has increased regardless of industry. According to Zsidisin (2003) and Colicchia & Strazzi (2012) supply chain risks can be seen as the probability of disruptions that prevent the purchasing company to meet its customers' expectations. This has notified also in the case company and the management supports development of supplier risk management and development steps have taken even though there is still lot of work to be done until supplier risk management is on top level. One of the driving forces for the improvement of supply chain risk management is insurance companies' ability to understand supply chains vulnerability (Norrman & Jansson 2004). This is supported by the interviews as the case company collects information for big disruptions and utilize business impact analysis for ensuring that insurance fees are not too high.

Low-cost country sourcing and its efficient management are highlighted as important factors in the case company. It is extremely important to find balance between savings and risks because potential disruption costs may be significantly higher than achieved savings. This challenge relates especially Europe as the business is not that attractive for suppliers and supplier base is smaller than for example in China. Low-cost country sourcing and its risks are notified in the earlier literature as well since it is stated that purchasing from low-cost countries grows the length of supply chain and if disruption strikes, costs will typically exceed the advantages of low-cost country sourcing (Kirilmaz & Erol 2017). In addition, it can be seen that low-cost country sourcing increases interfirm dependencies and thus makes supply chains more vulnerable (Christopher & Peck 2004).

Tang (2006a) presented five interrelated issues relating to supply chain management: 1) supply network design, 2) supplier relationship, 3) supplier selection process (criteria and supplier selection), 4) supplier order allocation and 5) supply contract. All of these are seen important in the case company when

considering supply chain risks. Planning what kind of suppliers are selected into the supplier base and supplier relationships can be seen as the starting point of supplier risk management. When planning new component, it should be decided from where materials can be bought, for example price or quality leader. In ideal situation there would be at least two suppliers per material as the case company has dual source policy. However, it is pointed out that sharing volume between suppliers efficiently requires big total volume and thus there exist multiple single source situations which have higher disruption risk. Supply contracts in turn, have important role in defining responsibilities of parties if something goes wrong and supplier is not able to deliver materials because of disruption.

In earlier literature, supply risks are typically talked in the context of sourcing products (Christopher et al. 2011). However, there can be seen that supply risks relate also to suppliers' reliability, selection of supplier base, sourcing strategy and indirect risks such as property rights and brand image (Manuj & Mentzer 2008a; Lintukangas et al. 2016). The case company considers also supply risks in larger scale as supplier selection includes evaluation of multiple stakeholders. In addition, the role of especially indirect risks such as brand risk if customers notify delays were seen to be critical. However, companies must accept that there exist always risks and they have to develop risk mitigation strategies for managing existing risks (Kirilmaz & Erol 2017). Interviewees are also aware of this and certain amount of disruption costs are taken into account in the budget.

Chopra et al. (2007) regard that ignoring supply risks may lead to overutilization of cheaper and unreliable suppliers that increase the disruption risk and potential impact significantly. In practice, it is not that simple to favor more expensive and reliable suppliers since companies must balance continuously with costs and risks. Interviews pointed out that the case company has especially challenging situation in Europe which force it to use more low-cost country suppliers and increase the number of single source situations. It is seen that deploying continental strategy for managing suppliers would be important for managing supplier base more efficiently.

Earlier literature includes multiple different methods for classifying supply chain disruption types. Sheffi & Rice (2005) divides disruptions into three main groups which are 1) unexpected events such as natural hazards, 2) accidents and 3) intentional disruptions such as strikes or terrorism. Kleindorfer & Saad (2005) in turn, present more illustrative and commonly used classification: 1) operational disruptions, 2) natural hazards and 3) political disruptions. This classification is used as a frame in this research. These categories are identified also in the case company.

Operational disruptions originate either from internal sources or external events such as raw materials, people or technology (Mizgier et al. 2015). It is stated that recovery from operational disruptions is not typically quick. The most severe disruption event in this category are financial problems and bankruptcies. The case company has faced multiple disruption due to operational disruptions and it was pointed out that financial problems are growing risk especially in Europe. (Sheffi & Rice 2005) This research pointed out that operational disruptions such as financial problems and material issues are considered to belong among the most typical sources of supply chain disruptions.

Natural hazards in turn, can be seen to be more predictable as their probabilities can be estimated based on historical data (Sheffi & Rice 2005). This category includes disruption events such as earthquakes, floods and hurricanes. In addition, in this research also fire is examined in this category. It is argued that the impact of natural hazards has increased as a consequence of recent development since the length and complexity of supply chains have increased (Haraguchi & Lall 2015; Altay & Ramirez 2010). Natural hazards were considered to be crucial source of disruptions also in the case company and especially earthquakes, floods and hurricanes had caused disruptions during recent years. However, it was argued that natural hazards are the easiest disruption type to forecast as they are focusing on specific geographical areas.

Fire is seen as the most common source of disruptions (Allianz Global Corporate & Specialty 2015) The impact of plant fire may vary greatly from minor harm to

complete destruction (Blackhurst et al. 2018). This emphasizes the importance of proper mitigation and recovery strategy. Chopra & Sodhi (2004) described how supplier's fire had completely different impacts on Nokia and Ericsson because of their sourcing strategies. This emphasizes the risks of single source strategy and points out how suppliers' ability to absorb increased volume or new products flexibly may reduce the impact significantly. The interview results support these notifications, and six interviewees mentioned it specifically when considering earlier disruptions. There was recent experience about fire of single source suppliers but improved BCP and other supplier's capability to increase its volumes and implement new components had crucial roles in reducing the impact of the disruption.

The earlier literature names political disruptions as third main disruption category and it appears mostly on politically instable countries such as Ukraine or Egypt or in emerging countries which are depending on changes of economic factors in developed countries Banham (2014). In addition, political risk is higher for example in China which does not have democratic politic system and thus government may have interfaces with free companies (Olson & Wu 2011). The conducted study indicates that also political risks are seen important and they are relevant especially in case of Chinese suppliers' which may have problems for example with environmental laws. The potential consequence of political disruption may be shut down of entire plant. Laws were mentioned as a central disruption event by four interviewees and in addition of suppliers' actions against laws or location in country which has high political risk, it was emphasized that contracts should be made under favored countries' laws for ensuring intended responsibilities in conflict situations. In addition of these, interviewees regarded that cyber risks are the most significant single risk source in future.

According to the case study, supply chain disruptions may cause multiple different costs for the case company. The main cost elements are different expediting costs such as transportation costs and overtime work, using more expensive second source or repurchasing materials, delay penalties and loss of sales. Expediting costs were seen to be most common because even small disruptions may cause those if there are not excessive materials in warehouse. Implementing new

suppliers requires usually investments from the case company, purchasing price may be significantly higher and the quality can vary especially in the beginning. For this reason, rapid changes in supplier base with high volumes can be seen to have high risks. Delay penalties are consequence of inability to deliver products on agreed schedule and they may be remarkably higher than the price of single product. Loss of future sales in turn, were named as the ultimate impact of supply chain disruptions which may be the indirect consequence if the case company cannot fulfil customer promises.

The literature review supports these notifications about costs of supply chain disruptions. There can be seen both direct and indirect impacts as Bode et al. (2011) state. However, it is seen that measuring economic impacts of supply chain disruptions is challenging. Tang (2006a) points out the trade-off between additional costs and lead-times since investing on recovery increase costs but reduce the increase of lead-time. This is a decision that companies must made for developing their BCPs and risk mitigation strategy. According to Ellis et al (2010) supply chain disruptions weaken the ability to satisfy its customers and if they are not relying that the company is not able to continue normal production, it may cause loss of sales. In addition, Hendricks & Singhal (2005) and Bode & Wagner (2015) point out that supply chain disruptions may impact on stock price performance which is an addition to the empirical results.

Learning from disruption experiences is seen to be important for the future (Jüttner & Maklan 2011; Zsidisin et al. 2005) Also interviewees emphasized the importance of future development and continuous learning for mitigation of future disruptions costs. Also sharing risk and consequences of supply chain disruptions are impacting on disruption costs. If risks can be shared in a way that suppliers are taking at least half of risks, it can be said that this would help significantly in mitigation of disruption cost. Especially role of risk sharing contracts is highlighted. For this reason, contract negotiations are relating closely to risk mitigation. (Harland et al. 2003; Wakolbinger & Cruz 2011) The role of contracts and contract negotiations were also recognized by the interviewees since it is important to take into account for example the size of the supplier for selecting appropriate contract template in a way that responsibilities

and requirements for supplier's insurances are defined on right level. This is important because in case disruption occurs, the case company would have possibility to demand compensations either from supplier or from its insurance company.

Also, information sharing and supply chain wide visibility to disruption risks are seen to be important to consider for mitigating supply chain risks. Information sharing can be utilized for example in joint problem with supply chain partners. This may be useful for the entire supply chain since best practices can be implemented to all parties. (Kleindorfer & Saad 2005) In interviews, the importance of information sharing was mentioned mainly inside the case company but also with suppliers. However, suppliers' reliability and truthfulness of the information that suppliers are providing were seen as challenges. For reducing this mistrust between the case company and suppliers, the co-operation had been increased as BCPs are updated periodically which improve those quality and thus strengthen trust between parties. However, in general information sharing was seen as challenge for the case company and interviewees hoped more open and proactive communication.

Table 14 Summary of interviews

Main risk events	**Risk impacts**	**Controlling the financial impact**
- Fire - Power blackouts - Cyber-attacks - Material Issues - Suppliers' capacity issues - IT risks - Financial risks - ERP changes - Natural hazards - Regulation - Political risks - Risks are identified mainly on 1st tier	- Only a bit costs because recovery actions on good level - Expediting costs, especially transportation - Indirect costs of negative customer experiences - Depends on the level of disruptions - Delay penalty - Internal costs of additional work - Replacing components - Direct impact to margins	- Business continuity planning and mapping of risks - Defining responsibilities in contract negotiations (sufficient insurances) - Improving information sharing and co-operation would increase proactivity in managing supply chain disruptions - Supplier selection based on different segments - Evaluating financial risks

As a summary of research questions relating to the qualitative part of this research, the most important aspects were combined with earlier literature. The main findings of the research study over risk events, risk impacts and methods for controlling the financial impact are composed into table 14. Both earlier literature and the research study point out that supply chain disruptions can be divided into operational disruptions, natural hazards and political disruptions. Disruption events were analyzed based on this classification and it was identified that fire, natural hazards at large, suppliers' financial problems and laws were seen to be the most critical disruption events. In addition, in the research study cyber-attacks were named as the most significant disruption event in future. There can be seen multiple methods for mitigating costs of supply chain. First of all, contracts can be utilized for defining parties' responsibilities which have important role if disruption strikes. Also, information sharing and co-operation between suppliers can used for mitigating risks proactively. Interviews pointed out that also BCPs have significant role in mitigating disruption costs as they improve the quality of supply chain risk management. When it comes to the costs that upstream supply chain disruptions are causing to the case company, few costs were highlighted. Expediting costs were named to be most common since almost all disruption events are causing those. However, the highest costs come from implementation of new suppliers and delay penalties if customers are demanding those. At last, if customers are not relying on the case company's ability to fulfil promises, the consequence may be loss of future sales due to weaken brand image.

6.2 Business impact analysis calculation model

Business impact analysis relates closely to business continuity planning. The research study suggests that implementing business impact analysis model would provide important tool for analyzing critical suppliers and their impact based on supplier – product platform linkages in the context of large manufacturing company. This is supported by the literature as BIA is seen as a key part of business continuity management system (Torabi et al. 2014). Business continuity planning in turn is a

significant part of supply chain risk management (Forbes 2009). Hence, also BIA relates closely to efficient management of supply chain risks.

The main benefits of the business impact calculation model would be connecting suppliers with the final products which the case company delivers to customers and describing the potential loss of sales if suppliers are not able to deliver materials. The calculation model presents the extreme impact since it was assumed that the disruption would be so critical that suppliers are not able to deliver any materials. Hence, it can be said that the calculation model is a prioritizing tool that highlights suppliers which have highest business impact and this information may be used in business continuity planning where mitigation activities are defined. According to the literature BIA process consist of identifying the critical business functions, defining the impact of disruptions and examining cost consequences (Devargas 1999). It is also seen that the BCP process should always begin with BIA (Miller 2003; Sikdar 2011; Torabi et al. 2014).

The development process of business impact calculation model points out that several data sources must be combined for creating a database model which describes financial impacts of supply chain disruptions. According to Tjoa et al. (2008) BIA focuses on identifying business activities and functions, recognizing suitable resources and identifying scenarios which are causing severe impacts. Sikdar (2011) emphasizes the importance of data gathering and analysis for providing useful results to the management. This supports the use of versatile ground data which combines suppliers and the case company's units and products. What is more, it can be seen that the calculation model improves the overall business performance as it provides useful information to the management that assists in decision making.

In previous researches, it was highlighted that BIA identifies especially the short-term impact and this this information can be used to define how mitigation actions should be targeted (Wright 2011). According to Devargas (1999) the outcome of BIA may vary from the number of not sold items to an estimate of the potential loss. In this research study, the chosen result was an estimate of loss of profits which bases

process margins of product platforms and volume forecasts. Although, the results are presented based on one-year volume, supply chain disruptions do not typically impact that long since new suppliers can be implemented more quickly. Hence, short-term impact scenarios may be calculated from the yearly impact. This is supported by Tammineedi (2010) as he states that BIA should present the worst-case scenario.

Regarding to the development of the calculation model, Tammineedi (2010) and Torabi et al. (2014) argue that main objectives of BIA are identifying critical functions and key products, determining the potential impact to the organization and determining continuity measures. The development process included all of these objectives and the model provides information on supplier, product platform and supply unit level. All of these perspectives provide meaningful information that management may utilize in category or continental planning as well as in co-operation with risk management, sourcing and R&D.

The ready calculation model combines suppliers and the case company's internal operations for finding examining to which product platforms suppliers are linked. This model takes influences both from the theory related to BIA and the case company's internal business impact calculation model. The financial effect as an outcome of BIA is mentioned multiple times when considering what are critical measurements of BIA (Messer 2009; Miller 2003; Paunescu et al. 2018) This research study indicates that the use of new business impact calculation model will impact positively on the communication inside the company but also with suppliers as their impact can be pointed out to them. The internal communication becomes more efficient as critical suppliers and supplier-product platform combinations are identified and this information can be shared to relevant stakeholders. It is stated in earlier literature that as a result of BIA, a report is provided to the top management which they utilize for preparing BCP (Sikdar 2011). Internal communication was named as one of the current challenges relating to supplier risks in the research study and enhancing it with the new calculation model is one of its main benefits.

As a conclusion of this analyzing how business impact of supply chain disruptions can be calculated, it can be seen that there are multiple different methods for analyzing the business impact. In this research, suppliers' business impact was calculated based on loss of sales because existing data supported this point of view. The results of this research implicate that efficient combining of suppliers and product platforms provide information that can be utilized especially in supplier management but also when planning new components and what suppliers are used. The main advantage of global calculation model is that includes the case company's most critical suppliers and notifies the entire impact since same suppliers may deliver to multiple factories. This save time from collecting information from separate sources and estimating the impact. Thus, more time and resources may be used directly to planning how risks and probability of disruptions can be reduced. This will lead to better knowing of supplier base and the information of most critical suppliers can be used as leverage for explaining investments on risk mitigation. It was seen that examining supplier – product platform combinations produce significant added value by making analysis more detailed and revealing most critical combinations. Even though the calculation model itself brings plenty benefits, it is important that information will be shared to relevant stakeholders and model will be developed based on user experience. The aim of this business impact calculation model is to provide tool to identify most critical suppliers and provide valuable information for business continuity planning. Furthermore, the objective is to assist development of supply chain risk management in the long term as the supplier base can be managed more efficiently and high-risk dependency situations are avoided.

7. Conclusions

The aim of this thesis is to improve supply chain risk management by developing a calculation model for business impact of supply chain disruptions. In addition, second objective is to analyze supply chain disruptions which are most critical to the case company, what kind of costs disruptions are causing and how these costs could be mitigated. This thesis consists of theoretical part which presents earlier theories and empirical part which is divided into qualitative and quantitative sections. Qualitative interviews are utilized in analyzing supply chain disruptions from the perspective of the case company whereas the calculation model is developed based on the quantitative date of the case company.

Suppliers are in crucial role especially in manufacturing companies as suppliers' ability to deliver ordered materials defines if production can be executed as planned. For this reason, it is important to understand what the most critical suppliers are, and what kind of business impact the have. BIA identifies typically most critical functions and products and determines the potential impact. BIA provides management useful information that helps in prioritizing and in decision-making process for example whether implement second source supplier or not. However, there does not exist any general calculation model which could be implemented to company regardless its industry or size. Hence, the development of the calculation model bases on requirements of the case company and the available data but frames are defined based on theories in earlier literature.

Supply chain disruptions can be divided into three main categories as presented earlier in this research. There can be seen differences between these since natural hazards are focused on specific geographical areas and similarly political disruptions can be targeted to certain countries. Both of these are also quite easy to predict whereas operational disruptions may appear anywhere at any time. Also costs of supply chain disruptions vary significantly from minor delays to complete destruction of supplier's plant which shut down entire production. The total costs depend on the structure of supplier base since the more single source suppliers there exist, the higher risk and potential disruption costs are related to those. Thus,

companies have notified the importance of supply chain risk management, which enable mitigation of future costs and improve the efficiency of business processes.

Based on the calculation model, which is developed in this thesis, it is possible to make decisions proactively with the size of supplier base and suppliers' purchase shares that reduce the potential risk and reduce the potential impact of supply chain disruptions. This model combines suppliers' and the case company's product platforms and examines these combinations on supply unit level providing an effective tool for supplier risk management. For ensuring the effectiveness of the calculation model, it is important that data is up to date and available.

This thesis provides new supply chain risk management tool to the case company that focuses on identifying most critical suppliers and their potential business impact. The main benefits are the calculated business impact itself but also possibility to compare different scenarios and suppliers' purchase shares are benefits of this calculation model, especially in terms of the case company. The model enables also analyzing business impact of different supply units if supplier is delivering to multiple units. Hence, more time can be used to actual business continuity planning and other mitigating actions, which further improves the quality of supply chain risk management.

For managerial implications, this research offers valuable insight what need to be done for to effectively analyze the business impact of supply chain disruptions. Here, co-operation especially with sourcing, risk management, sales & operations planning and financial departments was in significant role as required input data was collected from multiple sources. This study emphasizes the importance of harmonizing the used data because if the format or templates varies between different units, it causes challenges to the reliability of the model and additional work when harmonizing the data manually. Hence, implementing standard templates for forecast and supplier data would increase efficiency also on general level and ease co-operation between different units. At this moment, for example used names of product platforms might vary significantly in different files which causes additional questions and confirmations if names are understood correctly.

When it comes to supply chain disruptions, managers should consider that there exist major differences how different disruptions occurs. Thus, implementing continental sourcing strategy which examines areas' typical risks and takes these into account in supplier selection would be beneficial. In global environment, it would be important to have effective communication between different units so that risks related to suppliers which deliver to multiple units are shared and there could be prepared to possible disruptions proactively. Based on literature and empirical findings, disruption costs consist of expediting, repurchasing or new supplier implementation and delay costs as well as indirect loss of sales. Managers should take into account that contracts have crucial role in sharing disruption costs if something has gone wrong. It would be important to have a legal team that supports in contract negotiation in order to unpleasant surprises would be avoided and all costs do not remain as a responsibility of the buying company. Nevertheless, for avoiding these situations, it is extremely important to have effective and open communication both inside the company and with suppliers. Supplier relationship with mutual trust is the key of sharing risk information beforehand and considering what kind of mitigation actions would be needed for reducing the risk level.

7.1 Limitations and future research

When it comes to the limitations, the timeline of this research prevents to analyze the actual use of business impact calculation model in the case company. However, because purchasing shares are agreed for quite long time, it take time until it is possible to detect changes due to the results of this model. Nevertheless, BCPs are updated two times in year and in this purpose, the results could be seen faster. Even though the benefits of BIA are presented in the literature, the actual effects are not included into this research.

This calculation model was also designed for the purposes of the case company and even though its components are general and existing also in other manufacturing companies, it cannot be implemented directly without closer analysis of business process and the structure of the supply chain. Thus, results of especially

the quantitative part in this research may not be valid for other companies. The focus of this research is only on upstream supply chain disruptions and possible business impacts of downstream disruptions are ruled out.

For future research, it would be interesting to study second tier suppliers' impact as this research pointed out that often the root cause of disruptions is on lower tiers. Thus, better knowing of second tier would provide information if there exist same sub-suppliers under first tier suppliers. However, this is challenging because all suppliers are not willing to share information about their suppliers and this might require strong reliability between parties. In addition, analyzing actual costs of supply chain disruptions would be beneficial to study. It would be interesting to analyze if there can be seen differences between different disruption types and if some types are causing higher costs, investing on mitigation of especially those events would provide significant savings in future.

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Appendices

Appendix 1. Interview Questions

Interview questions:

General:

1. What is your role in the company?

2. What kind of tasks your positions includes?

3. How long have you worked in your current position?

Supply chain disruptions in the strategy:

4. Which strategy is closest for you in your job (e.g. company, front line, unit, sourcing etc.)?

5. How your strategy notices supply chain disruptions?

6. How supply chain disruptions are identified, measured and rated? Does this affect to supplier selection?

7. How do you rate the level of supply chain risk management at this moment? How it could be improved?

Information sharing:

8. How is information related to supplier risks shared inside the company?

9. What kind of information related supply chain disruptions would useful to share?

10. How this information moves/is available for members of the organization?

11. How do you utilize information related to supply chain and supplier risks in your job?

12. How widely information related to supplier risks will be collected?

13. How would you define the quality and reliability of the information?

Disruptions' impact to the supply chain:

14. What kind of supply chain risks have you noticed or experienced?

15. What can you tell about their commonness?

16. Have you identified differences geographically?

17. What kind of costs supply chain disruptions cause?

18. How would you describe their profit impact?

19. How there have been prepared for these costs?

20. How these costs are directed to different sides of the supply chain?

21. What kind of information related to additional costs due to supply chain disruptions will be collected? How this has been organized?

22. How cost information will be utilized at this moment?

23. What kind of sanctions there are related to delays? Are there any sanctions inside the company?

Calculation model and its' utilization:

24. In what level business impact calculation of supply chain disruptions should be done in order that it would support management? (E.g. concern vs business unit vs front line vs customer project vs something else) Why?

25. Which members of supply chain should be included to the calculation model?

26. How business impact analysis should be utilized in business continuity planning?