Tampereen yliopisto

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MANAGING SUPPLY CHAIN VOLATILITY CAUSED BY MAJOR DISRUPTIONS

Creating a disruption preparedness scorecard

Master's thesis
Faculty of Built Environment
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February 2021

ABSTRACT

Pauli Qvintus: Managing supply chain volatility caused by major disruptions
Master of Science Thesis
Tampere University
Master's Degree Programme in Civil Engineering
February 2021

Natural disasters, extreme weather, trade disputes, critical supply shortages, financial problems and new surprising events periodically occur around the world. They often cause severe supply chain disruptions which reduce profitability and can even cause bankruptcy. Disruption response measures are becoming common with the increase of resilient supply chains and added visibility, when facing frequently occurring disruptions. However, the field still lacks studies and applications on supply chain disruption prevention and response methods, when dealing with major disruptions caused by events exogenous to supply chain processes. The goal of this research is to develop a tool that can evaluate a firm's disruption preparedness and offer a set of strategies for improving the ability to face disastrous events.

A literature review was conducted on material related to supply chain disruptions, supply chain vulnerabilities, supply chain risk management, natural disasters, risk mitigation strategies, country risk assessments and measures to assess different aspects of supply chains. The focus was on recent research and past case studies. The development of supply chain risk management methods and supply chains' resilience factors were also analysed. The framework selected was the supply chain volatility dimension division where institutional and environmental volatility contains national economic and financial volatility, exceptional environmental events and political and legal instability.

The selected disruptive events that matched the set framework were extreme weather, volcanic activity, earthquakes and tsunamis, diseases, terrorism and war, economic conflicts, financial crises, and labour strikes, as those events have caused major supply chain disruptions in the past. Event specific and general supply chain disruption risk mitigation strategies were sought out from literature and were also developed in this thesis, and they were divided into three time periods: before, during and after a disruptive event.

Measures for the evaluation of a supply chain's characteristics, which affect supply chain disruption preparedness, were formed with the input of fellow researchers. The measures represented weaknesses that have been witnessed to be the causes of severe problems, and the strengths which have limited damages when disruptions have occurred. These measures were determined by rating scales. Also, a location-based evaluation was performed where country risk assessments were used. The gathered data was then evaluated by supply chain disruption preparedness score equations which were created for the tool.

The final outcome was a comprehensive tool for quickly assessing a supply chain's preparedness for various disruptive event types that also offers a guideline on how to develop supply chain operations to decrease risk in supply chains.

Keywords: Supply Chain, Supply Chain Disruption, Business Continuity Planning, Risk Assessment, Supply Chain Visibility, Disaster Recovery, Risk Mitigation Strategies

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

TIIVISTELMÄ

Pauli Qvintus: Toimitusketjuhäiriöiden hallinta kriisitilanteissa
Diplomityö
Tampereen yliopisto
Rakennustekniikan DI-tutkinto-ohjelma
Helmikuu 2021

Ympäri maailmaa toistuu säännöllisin väliajoin luonnonkatastrofeja, äärisäätä, kauppakiistoja, pulaa välttämättömistä resursseista, taloudellisia häiriöitä ja uusia yllättäviä tapahtumia. Niistä usein aiheutuu vakavia toimitusketjuhäiriöitä, jotka vähentävät tulosta ja voivat aiheuttaa konkursseja. Keinot usein toistuviin toimitusketjuhäiriöihin reagoimiseksi ovat yleistymässä toimitusketjujen resilienssin ja läpinäkyvyyden lisääntyessä. Kuitenkin alalta yhä puuttuu tutkimuksia ja sovelluksia toimitusketjuhäiriöiden hallinnasta, kun häiriöiden aiheuttajana on suuret toimituskejun ulkopuoliset tekijät. Tämän tutkimuksen tavoitteena on kehittää työkalu, jolla voidaan arvioida yrityksen valmiutta kohdata toimitusketjuhäiriöitä ja tarjota toimenpide-ehdotuksia kehittääkseen kykyä selviytyä häiriöistä.

Kirjallisuuskatsauksessa arvioitiin toimitusketjuhäiriöitä, toimitusketjujen haavoittuvuuksia, toimitusketjun riskienhallintaa, luonnonkatastrofeja, riskienhallintastrategioita, maakohtaisia riskiarviointeja ja menetelmiä arvioida toimitusketjujen ominaisuuksia. Katsauksessa keskityttiin viimeaikaisiin tutkimuksiin ja aiempiin tapaustutkimuksiin. Toimitusketjun riskienhallintamenetelmien kehitystä ja toimitusketjujen resilienssia tutkittiin. Tutkimuksia tarkasteltiin toimitusketjun volatiliteettiulottuvuuden kannalta, jossa institutionaalinen ja ympäristöllinen epävakaus sisältää kansallisen taloudellisen ja rahoituksellisen epävakauden, poikkeukselliset ympäristötapahtumat sekä poliittisen ja oikeudellisen epävakauden.

Työhön valittiin asetettuihin raameihin sopivia tapahtumia, jotka ovat aiemmin aiheuttaneet merkittäviä toimitusketjujen häiriöitä: tulivuorenpurkaukset, maanjäristykset ja tsunamit, taudit, terrorismi ja sota, taloudelliset konfliktit, finanssikriisit sekä lakot. Tapahtumakohtaiset ja yleiset toimitusketjuhäiriöiden vähentämisstrategiat etsittiin kirjallisuudesta sekä kehitettiin tässä opinnäytetyössä ja strategiat jaettiin kolmeen ajanjaksoon: ennen häiriötapahtumaa, sen aikaiseen sekä tapahtuman jälkeiseen jaksoon.

Toimitusketjujen häiriövalmiuteen vaikuttavat mittarit toimitusketjujen ominaisuuksien arviomiseksi laadittiin kanssatutkijoilta saadun palautteen avulla . Mittarit edustivat heikkouksia, joiden on todettu aiheuttavan vakavia ongelmia sekä vahvuuksia, joiden on havaittu rajoittavan vahinkoja häiriöiden tapahtuessa. Lisäksi suoritettiin sijaintiin perustuva arviointi, jossa käytettiin maakohtaisia riskiarviointeja. Kerätyt tiedot arvioitiin lopuksi työkalua varten luotujen toimitusketjuhäiriöiden valmiusyhtälöiden avulla.

Työn lopputulokseksi muodostui kokonaisvaltainen työkalu, jolla voi arvioida nopeasti toimitusketjun valmiutta erilaisiin häiriötapahtumiin. Työkalu tarjoaa myös ohjeet toimitusketjun toimintojen kehittämiseen ketjun riskien vähentämiseksi.

Avainsanat: Toimitusketju, Toimitusketjuhäiriö, Liiketoiminnan jatkuvuussuunnittelu, Riskienarviointi, Läpinäkyvyys toimitusketjussa, Toipumissuunnitelma, Riskinarviointitoimenpiteet

PREFACE

“This is the thesis that I wrote to finish my degree. Thank you to everybody involved.”

...is the placeholder text I had written here when I first started formatting this document several months ago. To expand on that condensed statement, this has been a passion project of mine, as I got to select the topic myself and it now, being completed, serves the purpose of finishing my master’s degree programme at Tampere University.

And the people I want to thank are my family and closest friends for their support and motivation. I would also like to thank my supervisors Heikki Liimatainen and Erika Kallionpää for their guidance. I am grateful for all the friends I made during my studies.

Also, thank you Inkeri for everything.

Tampere, 26.2.2019

Pauli Qvintus

CONTENTS

ABBREVIATIONS

JIT	Just in time
BCP	Business Continuity Planning
ERM	Enterprise Risk Management
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
SCV	Supply Chain Volatility
SCVi	Supply Chain Visibility

1. INTRODUCTION

“Supply chain disruption” is becoming a fairly common term in everyday use. Disruptions range from small disruptions, such as cargo being delayed at customs, to major disruptions such as a hurricane preventing the use of all modes of transport, possibly destroying manufacturing facilities while also driving up demand of specific goods and causing excess of others.

A supply chain is the entire process that starts with unprocessed raw materials and ends with the final customer using the finished goods. It includes the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. Supply chains link many companies together, and all vendors, service providers and customers are links in the supply chain. (CSCMP 2013)

In the context of this thesis, major supply chain disruptions are ones which result from major disruptive events, crises, ‘black swan events’, exceptional environmental events, political instability, huge fluctuations in the stock markets etc. These are disruptions which occur on a regular basis, but ones where the exact date, event type and severity can be impossible to determine beforehand.

Supply chain costs vary depending on the industry. For example, pharma companies supply chain costs are approximately 2% of sales, whereas chemical companies average in the 10% range and retail around 5%. (McKinsey 2009) In simple terms, a firm, where a product’s total price consists of a 10% profit, could double their profits by lowering supply chain costs from 20% to 10%. The importance of reducing supply chain costs has been noted, but cost reducing methods like Just-in-time (JIT) manufacturing and sourcing from multiple different international sources has made supply chains fragile to disruptions.

Volatility is a tendency to change quickly and unpredictably. In supply chains this tendency to change affects upstream and downstream material flow. Unplanned fluctuations are not desirable, as efficient supply chains are built to be in motion predictably where forecasting plays a key role.

A tool to assess a firm's state of preparedness for supply chain disruptions could prove helpful in supply chain volatility management if correct measures can be found. The ability to know how vulnerable a supply chain is to disruptions, is the first step in combatting them. Analysing the results should help see which parts of the supply chain need the most improvement.

The main motivation for this thesis was to expand my own knowledge of supply chain disruptions as well as help the academic society take a step forward in the study of supply chain volatility management. The exact topic was refined by having several meetings with my supervisors.

1.1 Research objectives

The objective of this thesis is to better our understanding of the affects that natural disasters, pandemics and other large scale unpredictable and seldom occurring disruptive events have had or may yet have on the efficiency of supply chains. The aim is to prepare a way to assess preparedness for disruptions by developing a tool which can be used to evaluate a supply chains preparedness for major disruptions as well as hopefully help in dealing with smaller ones. The tool should include a scorecard to grade the current state of different aspects of the supply chain and provide a guideline on how to improve preparedness.

To complete this task, appropriate measures must be found. Recent developments in supply chain management will have to be analysed. What is also needed is insight on what sort of practices have been in place in supply chains, which have faced disruptions, and analyse how they have excelled or failed. The thesis will also touch on the subjects of business continuity management, supply chain risk management, crises management and disaster recovery to help in identifying measures. The usefulness of disaster resiliency is beneficial for both new supply chains and the modification of up and running supply chains.

It will also prove useful to look at similar tools, tools which are used in managing supply chains, in order to create a tool which is intuitive to use for supply chain managers.

After the appropriate measures have been identified, a numerical value will have to be assigned to each one to be able to give a clear reading of the current state of preparedness for disruptions.

1.2 Research questions

The two main research questions which this thesis is going to answer are:

1. What are measures that can be used to assess disruption preparedness?
2. How should the measures be valuated?

The secondary questions are:

- How have disasters etc. disrupted supply chains in the past?
- What risk mitigation strategies can be applied?

1.3 Material and research methods

An extensive literature review will best help in the forming of a preparedness scorecard. Select books and studies will be researched in order to find the most comprehensive and up to date information on handling supply chain disruptions. This is performed mainly with the use of Andor, which is Tampere University Library's discovery service, which links to academic research sites like ResearchGate and ProQuest's Ebook Central. The search terms are ones which correlate to the subject: supply chain, resilience, disruption, disaster, extreme weather, earthquakes, risk management, business continuity planning, country risk etc. Case studies are also examined to understand the past and apply what was learned to help dealing with the future.

In the Chapter 2, the thesis will start off setting a more specific framework for the thesis, and supply chain management is introduced with it's driving factors. In the Chapter 3, a comprehensive literature review on supply chain risk management and related fields will be conducted to understand the current state of the topic and identify how previous research can aid in answering the research questions. Chapter 4 introduces the identified disruptive event types in their subcategories and risk mitigation strategies are formed. The measures for assessing supply chain disruption preparedness are developed in Chapter 5 and equations for evaluating preparedness are formed in Chapter 6. The last chapter, Chapter 7, has an assessment of how well the work succeeded and proposes future research topics.

2. SUPPLY CHAINS AND FRAMEWORK

The term “Supply chain” will be used throughout this thesis, and for those unfamiliar with the term, a simple explanation is given by Plenert (2014) in the book Supply Chain Optimization through Segmentation and Analytics. In the book, a supply chain is defined as the thousands of steps involved in the process of starting off with a raw material and ending up with a finished product in the hands of a client. Those steps involve manufacturing, movement, flow of information and money, distribution etc. A failure in a single piece of the supply chain is a failure of the entire supply chain.

The subject of this thesis revolves around the disruptions in supply chains. There are several different terms to depict the outcome of an abrupt failure in a supply chain, as causes and effects determine the terms. One of them is volatility.

Supply chain volatility (SCV), from a manufacturer’s point of view, is defined as *‘unplanned variation of upstream and downstream material flows resulting in a mismatch of supply and demand at the focal firm’*. In a broader sense, SCV arises from five different dimensions (defined in figure 1): organizational volatility, vertical volatility, behavioural volatility, market-related volatility and institutional and environmental volatility. (Nitsche and Durach 2018)

Dividing SCV into dimensions and meta-sources helps to break aspects down so that we can take them on one-on-one. In this thesis we are going to focus on the institutional and environmental volatility dimension and the meta-sources national economic and financial instability, exceptional environmental events and political and legal instability. All of the disruption causes identified in this thesis will be made to fit those three categories.

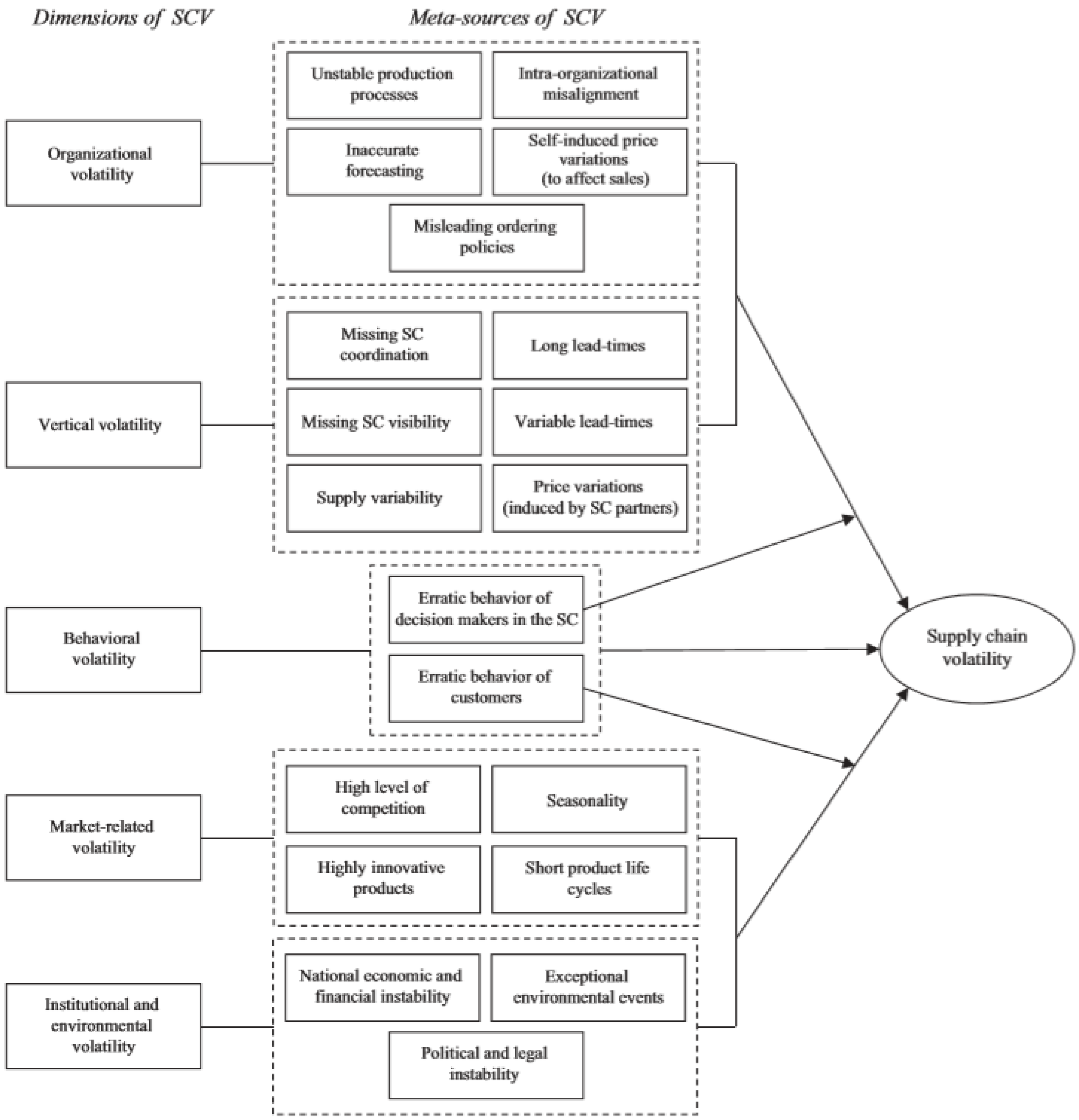


Figure 1 Dimensions of supply chain volatility (Nitsche and Durach 2018)

Nitsche & Durach (2018) also asked 17 supply chain professionals to evaluate how each dimension can be influenced, how often they are repeated and how large the relative deviating impact is. The results were that institutional and environmental volatility has the largest relative deviating impact and that it’s repetitiveness and influenceability are the lowest among all five dimensions. Although cases such as national economic and financial instability, political and legal instability and exceptional environmental events are mostly impossible to prevent by a single firm, there are actions which can be taken pre-emptively in order to shift excess costs elsewhere and keep supply chains in motion.

In a later study, Nitsche (2019) left out institutional and environmental volatility finding that it is case dependent, hard to influence and has a low repetitiveness. The focus of that study was to create a supply chain volatility assessment tool using systematic literature reviews, planned workshops and conceptual methods. (Nitsche 2019) Similar to the aims of this thesis, with the exception of Nitsche aiming for the creation of a broader SCV assessment tool of only the first four dimensions of supply chain volatility.

Several volatility indexes have been made to try to determine the state of volatileness in the stock market, such as the Chicago Board Options Exchange's Volatility Index VIX and S&P 500 1-Year Volatility Index VIX1YSM. Christopher & Holweg (2011) combined VIX with 7 other parameters, including exchange rates, shipping costs and raw material costs to develop the Supply Chain Volatility Index SCVI. Unfortunately, there doesn't seem to be an up to date version of the index available. It also wasn't made to help in managing micro-level volatility, but instead assess the volatility of the whole world's supply chains.

2.1 Supply chains, lean and agile

The steps involved with starting from raw materials to providing an end user with a finished product have developed over the years and global supply chains have driven the need for efficient management. Some of the terminology and methods in use are introduced here.

Supply chain management is essentially the planning and management involved with sourcing and procurement, conversion and all logistics management activities. It is also the coordination and collaboration with channel partners (suppliers, intermediaries, third party service providers and customers). Supply chain management integrates supply and demand management within and across companies. (CSCMP 2013)

SCM is an integrating function which is primarily responsible for linking major business functions and business processes within and across companies forming an efficient business model. It involves all logistics management activities and manufacturing operations, driving coordination of processes and activities in marketing, sales, product design, finance and information technology. (CSCMP 2013)

Lean focuses on reducing waste. In Lean, waste is defined as all non-value-added activities from the viewpoint of the customer. It is a team-based structure where continuous improvement is key. Historically, Lean hasn't been a part of supply chain management for a long time. It was first envisioned to be applied to the manufacturing industries assembly line manufacturers and was then applied by other types of manufacturing and became known as Lean Manufacturing. Lean Manufacturing is still a common term. In the beginning of the 21st century, offices and administrative processes started to apply

Lean and the term Lean Office was coined. Even more recently, Lean has been applied to the supply chain and logistics functions and has thus resulted in the popularization of Lean Enterprise. (Myerson 2012)

Lean can be implemented in all facilities and tasks included in supply chain management, from distribution centers to coordinating offices. Middle and upper management should assume the role of “out of the box” thinkers, performing tasks such as analysing and designing the flow of materials and information, while the whole organization is included in input, actual implementation and feedback (Myerson 2012).

In contrast with lean, where ‘waste’ is reduced to do more with less, agile is a flexibility approach, which is aimed at markets where demand is less predictable and the requirement for variety is high. It includes reducing complexity in organisational structures and in products. Agility requires a high level of shared information, visibility in downstream demand, and a high level of connectivity between supply chain partners. (Christopher 2000) This agility approach is better fitted to deal with the instabilities related to institutional and environmental volatility as lean has reduced ‘waste’, many of which could be useful redundancies for maintaining operations in disruptive times.

Supply chain agility can be divided into five dimensions, which are alertness, accessibility, decisiveness, swiftness and flexibility. Alertness is the ability to quickly detect changes, opportunities and threats. It requires being alert to market trends, customer needs, demand and impending disruptions. Accessibility is the ability to quickly access relevant data, so that when alertness has detected a change, the data needed to react to that change is quickly available. Decisiveness is the ability to execute required decisions effectively. Swiftness is the ability to implement the actions which are decided. And last, flexibility is the ability to modify tactics and operations. (Gligor 2015)

A firm’s supply chain’s agility performance can be assessed with the rating scales in Table 1.

Table 1 *Supply chain agility assessment (Gligor 2015)*

Type of variable	Statement
Z[1;7]	**Alertness** My company is quick to detect changes in its environment My company is quick to detect opportunities in its environment My company is quick to detect threats in its environment

Z[1;7]	**Accessibility** Our suppliers are quick to share relevant information with us Our customers are quick to share relevant information with us Usually, we can quickly access the data we need to make decisions
Z[1;7]	**Decisiveness** My company has processes in place that allow for quick decision making My company is fast at making decisions regarding supply chain operations My company is fast at making decisions regarding supply chain tactics
Z[1;7]	**Swiftness** When it makes decisions regarding a change in its supply chain operations my company can quickly implement it When it makes decisions regarding a change in its supply chain tactics my company can quickly implement it My company is quick at implementing changes to its supply chain
Z[1;7]	**Flexibility** My company’s suppliers can quickly meet an increase in order size My company’s suppliers can quickly adjust the specification of orders My company’s suppliers can quickly adjust/expedite their delivery lead time

3. SUPPLY CHAIN RISK MANAGEMENT

The field of supply chain risk management (SCRM) has focused on understanding and minimising risk in supply chains. Risk is relatively commonly defined as ‘possible damage or the potential loss of a net asset position, with no potential gains to offset it (Wolke 2017).

SCRM differs from traditional enterprise risk management (ERM). ERM is defined as “a process, effected by an entity’s board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives” (Maki et al. 2004). Definitions of ERM vary, but their principles remain similar.

The definition for SCRM also varies per source. One states that SCRM is “the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity” (Tang 2005). The more specific definition closest to our topic may be “the implementation of strategies to manage every day and exceptional risks along the supply chain through continuous risk assessment with the objective of reducing vulnerability and ensuring continuity”, having mentioned exceptional risks separate to every day risks. The fact that there is no universal definition for SCRM tells us that SCRM is a relatively new and evolving practice. (Schlegel and Trent 2016)

Companies have two main strategic options available for managing supply chain risk: risk mitigation and risk acceptance. With risk mitigation the supply chain’s risks are proactively avoided whereas with risk acceptance the supply chain’s risks are understood and accepted and are ready to suffer the negative impact if the risk materializes. (Blome and Schoenherr 2011) Linking the two strategic options to the previously mentioned dimensions of supply chain volatility, the first three dimensions (organizational, vertical and behavioural) are ones where risk mitigation is commonly used and the last two dimensions (market-related and institutional and environmental) mostly side on risk acceptance. For example, to combat vertical volatility, supplier performance scorecards can be used to mitigate risks and the risk of natural disasters are mostly accepted and dealt with by insurance.

Managers are aware of the need to protect their supply chains in case of high cost disruptions, but obvious solutions such as having multiple suppliers, adding capacity at different locations and increasing inventory, undermine efforts to increase cost efficiency in supply chains. Solutions to reduce risk must be weighed against supply chain cost efficiency to increase financial performance. (Sodhi and Chopra 2014) Once a disruptive event is dealt with and recovery from it is complete, firms should review learnt lessons and identify system refinements in order to reduce future risks, completing the supply chain resilience cycle of: Avoidance → Containment → Stabilization → Return → Review → Avoidance (Figure 2) (Melnyk et al. 2014).

Figure 2 *Supply chain resilience cycle*

3.1 Supply chain vulnerabilities

The transportation functions of supply chains basically consist of links and nodes. Nodes being warehouses, DCs, factories; essentially all places where the transportable items are planned to stop and every stop in the items' life cycle, up to the moment they are delivered to the client. Links are the means of connecting nodes to each other via transportation. Each link and node are important for the delivery of any product and can be seen as a vulnerability.

In an ideal situation, all nodes in a supply chain should have a value-adding role, yet their importance can be measured by evaluating their relative contribution to the supply chain's value. For example, a critical supplier supplying a critical component would be deemed more important, more critical, than a node supplying a noncritical component. Also, a node which integrates many equally valued parts into a larger component would be considered more valuable, more critical, than a node which integrates fewer parts of equal value. In addition, a node which handles deliveries to many other nodes, as distribution centers do, would be deemed more important, more critical than a node which handles deliveries to only a few other nodes. (Craighead et al. 2007) From a vulnerability standpoint, these more critical nodes can be seen as the more vulnerability inducing nodes of supply chains.

A critical node can be a sole supplier situation, where the criticality is determined by the risk associated with inflexibility. Having critical nodes in supply chains can cause major disruptions. “An unplanned event disrupting one or more critical nodes of a supply chain would be more likely to be severe than the same supply chain disruption affecting less critical nodes of the supply chain.” (Craighead et al. 2007) Some critical nodes are present in specific supply chains and others appear in all supply chains in differing severities.

Road and rail logistics form an entity which can, by themselves, form a complete the supply chain for material flow, unlike ocean shipping and air cargo, which need first and last mile transportation by pipelines, trucks or trains.

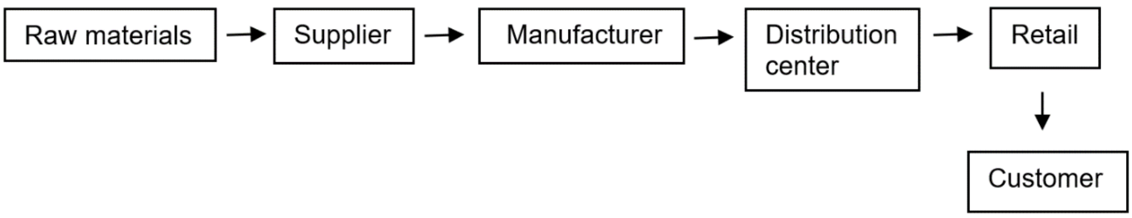


Figure 3 *Simplified supply chain material flow example*

A basic and simplified supply chain, material wise, is depicted in Figure 3. The arrows show material flow, and transportation can be carried out by any means. In todays globalised markets, it is typical to have global supply chains containing all main modes of transportation, especially in complex products such as electric cars and electronics.

Craighead et al. (2007) states that: “An unplanned event that disrupts a complex supply chain would be more likely to be severe than the same supply chain disruption occurring within a relatively less complex supply chain.” and “An unplanned event that disrupts a dense supply chain would be more likely to be severe than the same supply chain disruption occurring within a relatively less dense supply chain.” So, keeping sourcing local and the variety of modes of transportation simple, while simultaneously keeping distance between supply chain nodes, could have a positive effect on the increase of vulnerability in supply chains.

In domestic and intercontinental supply chains these modes of transportation can all be performed by road and rail transportation. Most often, freight transportation in road and rail transportation is handled separate to human transportation. Rail freight trains don't typically include passenger carriages and trucks seldom transport people.

In ocean freight, ports are a critical node because their location is fixed and aren't easily replaced. They are a complex part of the global maritime transportation system and thus particularly vulnerable. They often have an intermodal aspect to their operations, working as key hubs for transportation connections. The outgoing and incoming links can be highway systems, rail systems, pipelines, ocean shipping and air freight. The most usual link is road and rail. (Edgerton 2013)

A disruptive event at a seaport could be a longshoremen strike, where dock workers refuse to work, thus resulting in delays, especially when the supply chain depends on trained usage of heavy machinery at the port. A way to get around this issue is to have flexibility on which port your goods are routed through, given that the strike doesn't affect all nearby ports. (Craighead et al. 2007)

Air cargo's airports are tied to fixed locations similarly as ocean shipping's ports are. A differencing aspect is that ports can only be built on shorelines whereas airports can be built inland. Other dissimilarities are the need for heavy machinery in seaports and the differences in the type of cargo transported.

3.2 Scorecards and measures

An overview of different types of supply chain related scorecards will be reviewed to help in choosing the style of the disruption preparedness scorecard. Measures will also be identified from the following scorecards.

Data on suppliers and methods of data collection are an integral part of risk management and adding resilience. Knowing exactly what has happened and is happening is vital for forecasting what is going to happen. Volatility exists because of imperfections in supply chains and in order to reduce volatility, the imperfections must be identified and eliminated.

Most large firms have implemented performance measurement systems to evaluate their suppliers. The outputs of those systems are often called supplier scorecards. A review of a supplier scorecard system in a global logistics company revealed that there are huge differences between the experiences each department had had with a single supplier. There is a risk in using ineffective performance measurement systems and thus the performance measurement system should undergo evaluation to ensure the system is leading edge. (Schlegel and Trent 2016)

Supplier performance scorecard

One example of a supplier performance measurement system and supplier scorecard is a scorecard from IMI Precision (2015), in which supplier quality, delivery on time in full, purchase cost control and inventory management are measured in order to establish a supplier performance rating. This is a quantitative analysis approach where actual figures are examined. An example of the scorecard is presented in Figure 4.

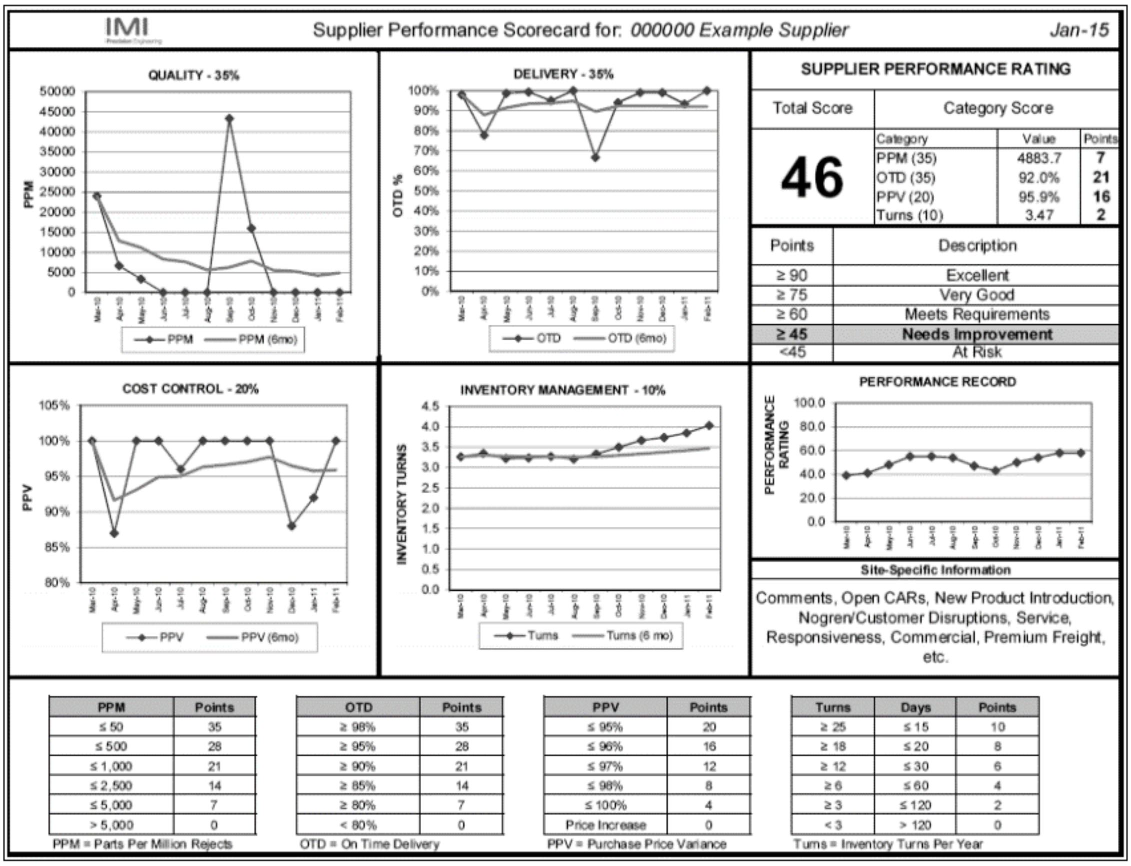


Figure 4 *Supplier performance scorecard example (IMI Precision 2015)*

Supplier quality is measured by calculating rejected parts per million (PPM).

$$\frac{Total\ Part\ Quantity\ Rejected}{Total\ Part\ Quantity\ Recieved} * 1\,000\,000 = PPM\ Figure$$

The quantity rejected is comprised of receiving inspection, production facility inspection or customer return or complaints. Supplier delivery on time in full (OTIF) is measured by calculating

$$\frac{Total\ Number\ of\ Deliveries\ Recieved\ by\ PO\ within\ Window}{Total\ Number\ of\ Deliveries\ Recieved\ by\ PO's} * 100 = OTIF\ FIGURE$$

The window, in this case, is set as 5 days early up to 0 days late for domestic suppliers and 10 days early up to 0 days late for international suppliers. Supplier purchase cost control measures the variation in price relative to the average price paid the previous year (PPV).

$$\frac{Actual\ Purchase\ Price}{IMI\ Precision\ Standard - Average\ Cost} * 100 = PPV\ Figure$$

The last figure which is measured is supplier inventory management (Turns).

$$\frac{Annualized\ Supplier\ Parts\ Usage}{Quantity\ Supplier\ Parts\ On\ Hand} = Turns\ Figure$$

The last calculation is made to monitor inventory levels. The figures are then scored based on their importance, giving a total score to the supplier. (IMI Precision 2015)

The scorecard looks to be well equipped to present continuously collected data and is able to give a score as an output as well as point out what the score means in terms of performance. The scorecard that we are going for in this thesis will be more of a one-off approach were regular evaluation isn’t needed, and the action list provided will be the end result for those trying to find ways of improving the disruption preparedness of their supply chains.

Supply chain visibility solutions scorecard

Another example of an evaluating system and it’s scorecard is McIntire’s (2014) supply chain visibility (SCVi) solutions scorecard (Table 2), in where sensitivity, accessibility, intelligence and decision relevance are evaluated in order to determine which possible solution would be the best to put into action. This is a qualitative analysis method where characteristics are evaluated.

Table 2. *SCVi solutions scorecard (McIntire 2014)*

Solu-tion	Sensi-tivity	Acces-sibility	Intelli-gence	Decision Relevance	Fit-ness	Solution Cost
A	1-4	1-6	1-4	1-10	x%	x€
B	1-4	1-6	1-4	1-10	x%	x€
C	1-4	1-6	1-4	1-10	x%	x€
D	1-4	1-6	1-4	1-10	x%	x€

This measuring tool wasn’t made to measure supplier performance, but it does reduce risk in the sense of giving supply chain managers more data. The figures are explained in the following tables (Tables 3-6).

Table 3. *SCVi sensitivity scoring (McIntire 2014)*

Score	Description
0	No data is captured to support the target business.
1	Some relevant data is captured, but it is incomplete.
2	All data is captured but the accuracy of the data is unknown or known to be low.
3	Data is complete and consistently biased (i.e. low quality but predictable).
4	All data needed to support the decision is captured, complete, consistent, and measurably high in accuracy.

Table 4 *SCVi accessibility scoring (McIntire 2014)*

Score	Description
0	Data remains in the capturing systems with no attempt to integrate the data for later use.
1	Data remains in the capturing systems, but processes allow them to be manually integrated for ad-hoc tasks.
2	The solution integrates all the decision-relevant data, but not all of it is retrievable by decision makers.
3	Data is integrated and available to the decision maker, but not using the methods they prefer.
4	All relevant data is integrated and accessible by any relevant path the decision maker could use.
5	All relevant data is integrated, accessible, and the approach to integrating data is easily adapted.
6	All relevant data is integrated, accessible, and the integration approach is self-updating when confronting new data types or sources.

Table 5 *SCVi intelligence scoring (McIntire 2014)*

Score	Description
0	There is no automated recognition from the solution that a business decision is needed.
1	Sometimes there is recognition from the solution that a business decision is needed.
2	The solution always knows that the business decision is needed.
3	The solution's approach to recognizing the need for a business decision is easily updated by users.
4	The solution's approach to recognizing the need for a business decision is self-updating.

Table 6 *SCVi decision relevance scoring (McIntire 2014)*

Score	Description
0	The solution has no explicit input to this business decision.
1	The solution is a required information source for the decision maker. A user decides how and when to make the decision.
2	The solution is a required information source for the decision maker. The solution decides when the decision is taken, and the user decides everything else.
3	The solution offers a set of action alternatives based on the event, or
4	narrows the selection down to a few, or
5	suggests one action, and

6	executes that suggestion if the human approves, or
7	allows the human a restricted time to veto before automatic execution, or
8	executes automatically, then necessarily informs the human, or
9	informs the human only if asked, or
10	the solution decides everything and acts autonomously, with no notice given to humans except for debugging.

The fitness percent score in Table 2 is simply formulated by summing all four scores together and dividing by the maximum possible score. The relative importance of each factor is taken into account by placing a higher possible score for decision relevance, which is considered the most important factor. (McIntire 2014)

This sort of 'picking the most relevant statement' for a scorecard seems cumbersome to read and evaluate. The functional part of it is however that is shows the next step in the development process which should be made. For example, if you rate your SCVi decision relevance a score of "3 – The solution offers a set of action alternatives based on the event", then you can easily see the higher scores are ones where the solutions offered should be narrower.

<u>Supply chain volatility scorecard</u>

In the development of a benchmarking instrument to assess supply chain volatility, Nitsche (2019) was able to identify several measures for the first four dimensions of supply chain volatility (organizational volatility, vertical volatility, behavioural volatility and market-related volatility). The measures were arrived at by choosing appropriate measures based on previous studies and then refining them by incorporating feedback from two fellow researchers and a supply chain practitioner.

The variables and explanations for why they were chosen will be reviewed in an effort to help identify measures for the major disruption preparedness scorecard. Some of the measures identified in the following charts could possibly also be used to evaluate the preparedness for dealing with institutional and environmental volatility.

Organizational volatility covers the focal firm's self-induced volatility, which can be assessed by using the measures shown in Table 7. Organizational volatility, presented by Nitsche & Durach (2019), includes the meta-sources: unstable production processes, inaccurate forecasting, intra-organizational misalignment, self-induced price variations and misleading ordering policies. Inaccurate forecasting is measured by using the forecasting performance measure mean absolute percentage error (MAPE).

The rest of the meta-sources are evaluated by choosing the most correct statement. Having just three stated options looks easier to interpret than the up to 11 statements in the previous SCVi scorecard.

Table 7 *Organizational volatility measures (Nitsche 2019)*

Variable name	**Type of variable**	**Description**
OA_1	Z[1;7]	Level of planning process formality 1: no formalized planning process 4: moderately formalized planning process 7: internally completely formalized planning process
OA_2	Z[1;7]	Level of promotions planning integration 1: no promotions and price changes planned 4: issues like promotions and price changes are planned and considered but insufficiently performed 7: issues like promotions and price changes are planned and considered sufficiently throughout the whole organization
OA_3	Z[1;7]	Efficiency of information availability and exchange 1: information is only partially available including many redundancies 4: partially centralized information storage; moderate friction losses in information flows 7: people receive only information they actually need; no friction losses in cross departmental information flows
OA_4	Z[1;7]	Level of planning efficiency 1: no alignment of plans throughout the company 4: due to rudimentary alignment of plans, frequent re-planning is required 7: due to sufficient alignment of plans, re-planning becomes very rare
OA_5	Z[1;7]	Level of assignment of roles and responsibilities 1: no concrete assignment of roles and responsibilities with regard to planning tasks and activities 4: roles and responsibilities are clearly defined but not yet successfully implemented; no dedicated planning process owner; people partially held accountable for their plans and performance 7: dedicated planning organization responsible for planning process owner and role descriptions; planning organization entirely aligned with the business
OA_6	Z[1;7]	Level of integration of planning systems of different business functions 1: heterogeneous spreadsheets existent and in use 4: information from other systems need to be manually entered or uploaded (no interfaces)
MAPE1f	R[0;1]	1-month ahead MAPE (family level)
MAPE3f	R[0;1]	3-month ahead MAPE (family level)
MAPE6f	R[0;1]	6-month ahead MAPE (family level)
MAPE1v	R[0;1]	1-month ahead MAPE (product variant level)
MAPE3v	R[0;1]	3-month ahead MAPE (product variant level)
MAPE6v	R[0;1]	6-month ahead MAPE (product variant level)

An organizational volatility score is then calculated from the gathered measures. The score is derived from the mean of the mean of variables OA_1 through OA_2 and SC_{MAPE}.

$$\mathrm{SC}_{OV} = 0.5 * SC_{OA} + 0.5 * SC_{MAPE}$$

SC_{MAPE} is derived from the weighted values of the different MAPE variables, giving more importance to the accuracy of near future forecasts.

$$SC_{MAPE} = 0.3 * SC_{MAPE1f} + 0.3 * SC_{MAPE1v} + 0.15 * SC_{MAPE3f} + 0.15 * SC_{MAPE3v} + 0.05 * SC_{MAPE6f} + 0.05 * SC_{MAPE6v}$$

The weighting of the MAPE variables is stated to be questionable, but was decided on with the input of multiple supply chain practitioners. (Nitsche 2019) The development of assessment tools requires some educated guesses on what the best weighted scoring model should be. The OA variables are all perceived as equal in this model. One could argue though, that information availability and exchange is more important than promotions planning integration, or the other way around, when assessing supply chain volatility. A trial and error approach could prove useful in the long run, with continual fine tuning of the weighting model. Then again, the weighting could be argued to not have a very significant role in the outcome, as here the goal is to be able to benchmark the focal firm's supply chain's level of volatility against other firms' supply chains' levels of volatility.

The measures of vertical volatility are variables related to the metrics involved with transportation time and precision (Table 8). It is assumed that the focal firm tracks the performance of suppliers, manufacturing and deliveries to be able to fill in these values quickly and precisely.

Table 8 *Vertical volatility measures (Nitsche 2019)*

Variable name	Type of variable	Description
LTS_i	R [0;∞[	Supplier lead time of supplier *i* in days
LTT_i	R [0;∞[	Transportation lead time from supplier *i* in days
LTP	R [0;∞[	Production lead time in days
LTC_j	R [0;∞[	Delivery lead time to customer *j* in days
$OTDS_i$	R [0;1]	On-time delivery rate of supplier *i*
$OTDC_j$	R [0;1]	On-time delivery rate to customer *j*
SP_i	R [0;∞[	Time window of arrival of majority of goods (95%) of supplier *i* *(longest time span – shortest time span between ordering and receiving an item)*

The assumption that firms have the correct data to use could be detrimental to getting benchmarkable scores as missing data could lead to estimations and thus errors. However, close monitoring of suppliers' performance is a crucial part of managing vertical volatility and could be seen as a baseline requirement for filling out the form.

The erratic behaviour of customers and decision makers is assessed by using a 7-point Likert scale in Table 9. Behavioural volatility was stated to be one of the most acute sources of total SCV (Nitsche and Durach 2018).

Table 9 *Behavioral volatility measures (Nitsche 2019)*

Variable name	Type of variable	Description
EBC_1	Z[1;7]	In general, our customer demand is very hard to predict.
ECB_2	Z[1;7]	Market trends are difficult to monitor because customer preferences change constantly.
ECB_3	Z[1;7]	Our customers often adjust already placed orders.
ECB_4	Z[1;7]	Customer loyalty to our brand is relatively low and the customer changes its preferences constantly.
ECB_5	Z[1;7]	Our customers often adjust orders (quantities or other specifications) in a short time window before planned delivery.
EBD_1	Z[1;7]	At the end of the year we order more than we actually need to get a cash-back from our supplier.
EBD_2	Z[1;7]	Sometimes we order more than actually needed in order "to be safe".

EBD_3	Z[1;7]	Sometimes we order less than actually needed in order to reduce our safety stock level.
EBD_4	Z[1;7]	Due to lack of confidence in our IT system we adjust order quantities that are generated by the system based on personal feelings.
EBD_5	Z[1;7]	Due to lack of confidence in our IT system we adjust forecasts that are generated by the system based on personal feelings.
EBD_6	Z[1;7]	When we expect a shortage of a component (not clear yet), we order more than actually needed.
EBD_7	Z[1;7]	Salespeople place customer orders early in advance before an actual customer order exists.
EBD_8	Z[1;7]	If the actual demand in one month is higher or lower than planned demand, we immediately adjust our future plans.
EBD_9	Z[1;7]	If we expect a price increase in the near future, we order more than ewe actually need to benefit from the current price.

Here, ranking each statement on the spectrum from 1: totally disagree to 7: totally agree, has a self estimation quality which can be fast to execute, but may lead to imprecise results. For example, two separate manufacturing firms with the same customer base could have a totally different opinion on whether their customer demand is very hard to predict or not. This method could cause problems in a benchmarking tool but may prove useful in the disruption preparedness tool formed in this thesis, as the exact values of preparedness aren’t important for the functionality of the tool.

The last table of variables (Table 10) uses a rating scale again, this time to determine the perceived level of market related measures.

Table 10 *Market related volatility measures (Nitsche 2019)*

Variable name	**Type of variable**	**Description**
HC_1	Z[1;7]	We often lose customers to our direct competitors.
HC_2	Z[1;7]	We are forced to an intensive price competition with our competitors.
HC_3	Z[1;7]	We often have to rely on the same suppliers as our direct competitors.
HC_4	Z[1;7]	In our market, it is difficult for us to differentiate ourselves from our competitors.
HC_5	Z[1;7]	We offer a high number of product variants of our representative product.
HC_6	Z[1;7]	There is a high number of substitutes for our representative product at the market.

Moreover, weighting factors α are introduced for the final goal of calculating the overall SCV score. α has three forms an it either depends on the production strategy or is independent from the production strategy (Table 11).

Table 11 *Weighting factors (Nitsche 2019)*

Weighting factor	**Independent from production strategy**	**Make to order production strategy**	**Make to stock production strategy**
α_{OV}	0.341	0.451	0.277
α_{VV}	0.276	0.296	0.234
α_{BV}	0.203	0.168	0.187

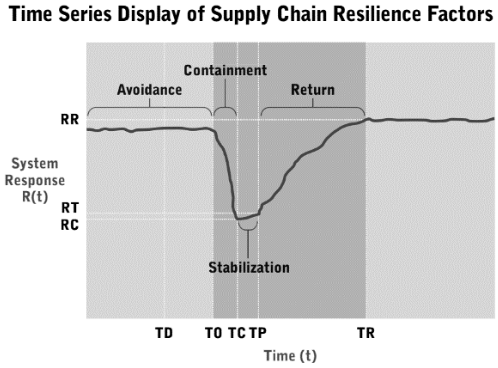
α_{MV}	0.179	0.085	0.301

To continue this research on managing volatility in the different dimensions of supply chain volatility, institutional and environmental volatility will be similarly sectioned, and an evaluation model will be built in this thesis.

3.3 Supply chain resilience

The concept of resilience came to be from the works of ecologist C.S. Holling back in 1973. His work on noting the characteristics of a resilient ecological system has since been applied to the fields of psychology, systems thinking, disaster management, and more recently, supply chain management. Melnyk et al. (2014) define supply chain resilience as “the ability of a supply chain to both resist disruptions and recover operational capability after disruptions occur”, which is similar to supply chain continuity planning and disaster recovery, which will be further investigated later in this research. For others, resilience can be seen as a reactive capability that occurs after a disruption or shock has taken place, or as more proactive measures toward helping to prepare for a disruption. (Melnyk et al. 2014)

Supply chain resilience consists of two critical and complementary system components: the capacity for resistance and the capacity for recovery. Resistance capacity is “the ability of a system to minimize the impact of a disruption by evading it entirely (avoidance) or by minimizing the time between disruption onset and the start of recovery from that disruption (containment)”. Recovery capacity defined as: “The ability of a system to return to functionality once a disruption has occurred. The process of system recovery is characterized by a (hopefully brief) stabilization phase after which a return to a steady state of performance can be pursued. The final achieved steady-state performance may or may not reacquire original performance levels, and is dependent on many disruption and competitor factors.” (Melnyk et al. 2014)



Description of Time Series Inflection Points

Event	Type	Full Name	Operational Definition
TD	T-Time	Time of Disturbance	Specific time period in which the triggering event is initiated.
TO	T	Time of Onset	The time period in which the system being studied feels the impact of the triggering event.
TC	T	Time of Climax	Time period in which the system reaches its climax.
RC	R-Response	Response at Climax	The system response at the climax.
TP	T	Turning Point	The time period in which the system begins to recover from the disturbance.
RT	R	Response at Turning Point	The system response at the turning point; the response at which the system transitions from being impacted by the disturbance to recovering from the disturbance.
TR	T	Time of Recovery	The time period in which the system returns to steady-state.
RR	R	Response at Recovery	The system response level at the recovery period (may differ from the pre-disturbance response level).

Figure 5 *Supply chain resilience factors and descriptions of time series inflection points (Melnyk et al. 2014)*

Experiences with new markets and added knowledge of product life cycles should help evolve supply chains over time. Pooling recurrent risk and minimizing supply chain costs by centralizing capacity can be done in early stages when sales are low and demand uncertainty is high, but to become more responsive to local markets and to reduce risks, capacity could be more decentralized as sales increase and uncertainty declines. (Sodhi and Chopra 2014) Actions taken before a supply chain disruption would fall under the 'Avoidance' sector depicted in Figure 5, or as premeasures in preparation for 'Containment'.

Regionalizing supply chains can enable the containment of the impact of a supply chain disruption, so that losing the supply of a disrupted area is contained within that area. The 2011 tsunami in Japan caused serious delays for Japanese automakers as plants worldwide relied upon the supply of parts which could only be sourced from the tsunami-affected regions of Japan. (Sodhi and Chopra 2014) In a closer examination of the effects of the tsunami and lacks in resilience, both Toyota and Nissan were unequipped to handle a disaster of this severity. However, Nissan was able to make a speedier recovery and regain lost market share faster than Toyota. The cause of Nissan's faster recovery phase was Nissan accessing alternative suppliers as Toyota stuck to existing suppliers. (Melnyk et al. 2014)

In a similar example of a supply chain disruption involving two major companies, Ericsson and Nokia were both affected by a fire in a Philips Electronics plant in New Mexico. The plant was supplying both companies with critical mobile phone chips and while it took Nokia three days to find an alternative supplier, Ericsson lost several weeks of production costing it hundreds of millions of dollars during the period. The ability to regroup cost Nokia upfront and paid off in terms of less disruption. (Sodhi and Chopra 2014)

Regionalizing supply chains often also helps companies reduce shipping costs while avoiding a part of the supply chain to be severely disrupted by region specific natural disasters or geopolitical flare-ups. In a regionalized system, disrupted regions can be temporarily served by supply chains in neighbouring regions. For example, some Chinese and Indian textile manufactures have started to set up plants in the United States where labour costs are higher therefor “de-risking” their overall supply chain and cutting shipping costs and time. (Sodhi and Chopra 2014)

Information technology systems can also be used to help increase supply chain resilience. Delivery and sales figures are already often used to monitor material flows, while productions schedules, demand forecasts and information about quality is used to avoid recurring risks and enhance performance. Leveraging these information technology systems to contain the impact of supply chain disruptions by enabling swift reaction times is a win-win situation in dealing with costs and risks. For further benefits, companies and their partners can develop contingent recovery plans for different types of disruptions in advance to shorten the time needed for designing new supply chains. For example, Li & Fung Ltd. is a contract manufacturing company based in Hong Kong and has a variety of contingent supply plans which enable shifting from a supplier in one country to another supplier in a different country. (Sodhi and Chopra 2014)

3.4 Supply chain visibility

Visibility is important when dealing with major supply chain disruptions. Knowing the status of each part of the supply chain is essential, knowing which links and nodes are operational, knowing what the status of alternative sites and routes are, and most essentially, knowing where the goods are at any given moment, and how many of them there are.

Efforts have been made throughout the years to better visibility in enterprises and various visibility increasing systems have been put into practice, such as electronic data interchange and tracking systems.

For example, a supply chain control tower is a sophisticated approach to increasing supply chain visibility. A supply chain control tower can be a huge room with lots of monitors, similar to NASA’s mission control centers, or a smaller setup with the whole end to end supply chain visible.

Banker (2019) describes a supply chain control tower as one that: covers an end to end supply chain process, has visibility to how exception events affect the existing supply chain plans, visibility on customer service and financial implications from exceptions, offers fairly seamless scenario planning, has timely, clean and accurate data, has intuitive views e.g. Google map views, is a collaboration platform, includes disruption simulations, has machine learning and artificial intelligence to include predictive capabilities and must accommodate changes to existing processes. Risk assessment tools could be incorporated into supply chain visibility applications for the ability to view existing and simulated levels of risk and their possible impacts.

3.5 Business continuity planning

In supply chain management, business continuity planning (BCP) is the approach adopted by many supply chain practitioners to deal with the hard to predict, seldom occurring disruptions, which when occur, immediately and significantly impact the supply chain's ability to meet customer demands. BCP was developed to reduce the amount of varying effects which unanticipated events could pose on the focal firm's ability to meet customer requirements. Supply chain managers are now expected to plan for and manage disruptions. The responses taken to manage potential risks can be sorted into three categories: reduce the probability of disruptions, reduce the impact of disruptions once they occur or the combination of the two. (Zsidisin *, Melnyk, and Ragatz 2005) In the event of a new major disruption, e.g. Covid-19, a whole new type of hard to anticipate event might be hard to take into account when trying to reduce the probability of disruptions.

An online survey, carried out by MIT Center for Transportation and Logistics, which gathered 1461 complete responses from 73 countries, found that professional supply chain managers were more likely to choose prevention over response in supply chain risk management. Of all the respondents, 44% chose prevention, 30% chose both and 16% chose response when asked whether they should invest in planning and implementing risk-prevention measures and/or planning and practicing event-response measures. The responses were even more on the prevention side when only accounting for respondents who identified themselves as supply chain risk managers. (Arntzen 2010) The more 'prevention' leaning answers could be accounted by the hypothesis that there was still a clear lack of investment in risk prevention measures even for more frequently occurring known risks and that only few respondents felt that they were ready to invest in response, which is better suited to handle new and surprising risks.

Arntzen (2010) also noted that the MIT CTL survey results ranked 'earthquakes and tsunamis' as the least important in terms of relative importance. Viewing institutional and environmental volatility i.e. earthquakes or political instability as something that can't be prevented can cause a major disregard for even considering them in risk mitigation strategies. This thesis will aim at providing both risk prevention methods as well as response measures.

In addition to business continuity planning, disaster recovery is a separate field where emphasis is placed on ensuring that business operations continue when a disaster strikes and on making sure that the recovery happens in the shortest possible time. Disaster recovery planning strategies can be divided into three sections: preventive, anticipatory and mitigatory. A preventive strategy aims at preventing disasters from happening. The most important functions of an organisation are secured and made reliable to reduce the affects of disasters which are under the organisations control. This includes the elimination of bugs, configuration errors and hardware failures. Anticipatory strategies require the identification of procedures needed to respond to and recover from disasters. Scenarios that are likely to result in a disaster are predicted and their affects are estimated. Mitigatory strategies are used to minimize the impact of disasters that can’t be avoided. (Sandhu 2002) Mitigatory strategies and anticipatory strategies are the ones used in this thesis as the disruptive events in the volatility dimension of institutional and environmental volatility can’t be prevented by a single firm.

4. INSTITUTIONAL AND ENVIRONMENTAL VOLATILITY

The five dimensions of supply chain volatility, proposed by Nitsche & Durach (2018), has institutional and environmental volatility divided into three meta-sources: national economic and financial instability, exceptional environmental events and political and legal instability. These three meta-sources are now divided into their own meta-sources which are formed from historically occurred major disruptions.

The different major disruption causes identified here are ones which have come up most frequently in researching supply chain disruptions. A year ago, diseases probably wouldn’t have made the list, and a decade or two from now it could be hard to understand why an obvious disruption cause (e.g. the internet going down or sea level changes) has been left out.

Nitsche & Durach (2018) propose that institutional and environmental volatility is characterized by having a high relative deviating impact on SCV, having a low degree of repetitiveness and also a low degree of influenceability. The low degree of influenceability is explained as: “Institutional and environmental volatility is characterized by a relatively low degree of influenceability since a relocation of own facilities or SC partners is necessary to overcome some of the obstacles induced by this dimension.” One could argue though that relocating your own facilities and switching SC partners isn’t something that can’t be influenced, especially in cases where the supply chain is only just being planned. Also, avoidance isn’t the only measure which can be taken to manage institutional and environmental volatility.

The variability of influenceability is high throughout institutional and environmental volatility. For example, building your entire supply chain to be located in the middle of a tectonic plate should be enough to be able to influence the harm caused by an earthquake to non-existent. Yet, the same supply chain could still be affected by a financial crisis or a pandemic.

Dividing past and ongoing disruptions into the thee stated meta-sources is tricky in the case of pandemics. Pandemics and epidemics could be the result of biological warfare and filed under political and legal instability, but they are essentially biological, thus relating to nature, so we can place them under exceptional environmental events. There isn’t a clear slot for pandemics, which could be yet another indicator that major disruptions caused by exceptional events are difficult to forecast.

4.1 Exceptional environmental events

For many, the first to come to mind when talking about disasters are environmental events such as earthquakes or volcanoes erupting. They are also beginning to be learnt how to deal with to ensure continuous supply chain operations.

4.1.1 Extreme weather

Extreme weather can cause various adverse effects such as floods or flying debris due to high wind speeds. The disruptions caused by extreme weather can be felt around the globe in today's global supply chains. For example, a 2011 flood in Thailand caused hard disk manufactures to halt production, which in turn caused pile ups at Intel's warehouses as original equipment manufacturers couldn't complete the whole product (Christ 2014).

Extreme weather caused damages have seemed to worsen over the last years. Billion-dollar weather disasters in the U.S have increased from the last 40-year average of 7.0 events per year to the last 5-year average of 16.2 events per year, where the damages are direct losses amounting from "physical damage to residential, commercial and government/municipal buildings, material assets within a building, time element losses (i.e., time-cost for businesses and hotel-costs for loss of living quarters), vehicles, public and private infrastructure, and agricultural assets (e.g. buildings, machinery, livestock)". (NOAA 2021)

Mitigation strategies

The chosen mitigation strategies are fit to work for different types of extreme weather, from flooding to extreme cold. The mitigation strategies here are similar to mitigation strategies concerning seismic activity.

A roundtable was held by MIT's Humanitarian Response Lab at the Center for Transportation and Logistics on supply chain resilience with hurricanes as a focal point. Their multiple day discussions brought forth several tactics which had proved useful in disruption management. A summary report was issued which listed mitigation strategies from which the most relevant were chosen to be incorporated in this thesis and they are listed, among with other mitigation strategies, in Table 11. (MIT CTL 2017)

Table 12 *Extreme weather supply chain risk mitigation strategies*

Before a crisis	**During a crisis**	**After a crisis**
If possible, plan essential shipments around hurricane season etc. Invest in an early warning system	Accumulate and relocate resources Implement work at home opportunities	Check for all damages and file insurance claims Fix noticed structural vulnerabilities

Plan and train for work at home as people might not be able to get to the workplace during extreme weather Insurance is vital in locations where avoidance isn't possible Relocate inventory in preparation for incoming extreme weather: pull unneeded inventory from vulnerable locations and stock items in threatened region to cover pre-storm and post-storm surges in demand	Switch to alternative suppliers if needed Secure electricity and IT-capabilities, possibly buy generators Reroute shipments as possible Help local efforts in repairing infrastructure Consider giving aid to the families of your employees to ensure employees' ability and willingness to work	Consider moving operations from risk area to mitigate future losses Update forecasting as needed Move inventory to accommodate for steady times

4.1.2 Volcanic activity

In 2010 the eruptions of Eyjafjallajökull in Iceland caused a volcanic ash cloud to form over Europe. Grímsvötn erupted just over a year later causing similar results, which also occurred in Iceland. The volcanic ash caused air traffic to close in most European countries for several days. (Bente 2014)

The air traffic crisis in April 2010 caused 104 000 flights to be cancelled and the main period was only 8 days long, 15th-22nd April. Especially in Scandinavia and Iceland the effects started earlier and continued later than in other countries. (EUROCONTROL 2010)

The disruptions were largest on the 17th of April through 19th of April, and they resulted in lost revenues estimated to be 400 million USD per day and affected roughly 1.2 million passengers a day, which at the time accounted for an estimated 29% of global air traffic. (Bente 2014) The huge reduction of air traffic can clearly be seen in Figure 6.

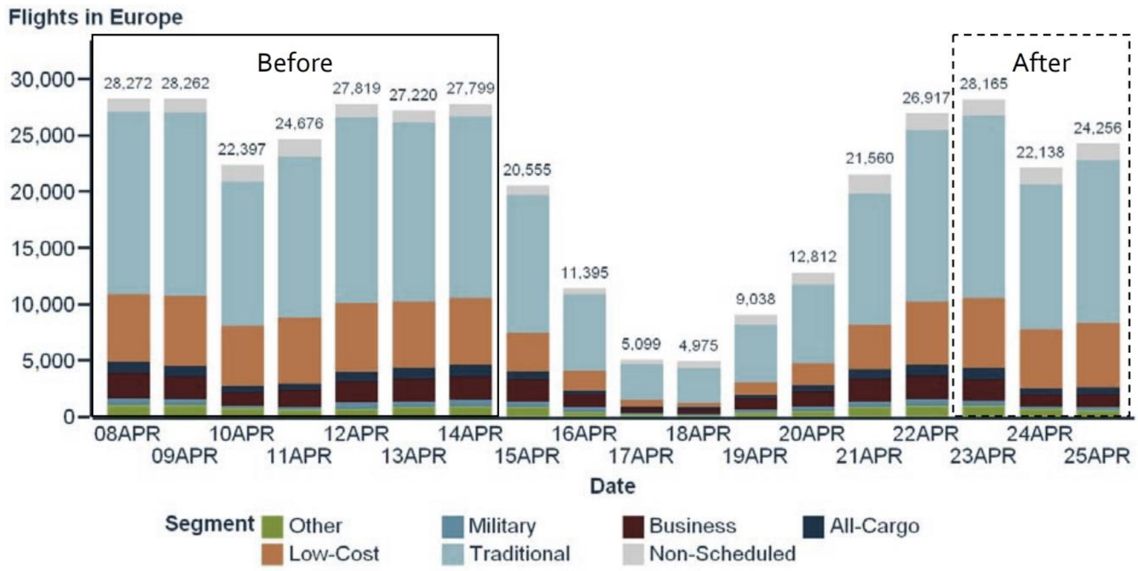


Figure 6 Air traffic in Europe in 2010 (EUROCONTROL 2010)

During the main 8 days of the incident, 2 900 cargo flights were cancelled. A large portion of cargo gets transported in the bellies of passenger planes, so the overall effect on delayed goods was higher resulting from the 92 000 cancelled passenger flights (Low-Cost, Traditional and Non-Scheduled). (EUROCONTROL 2010)

The volcanic eruptions can be forecasted and the situation in Iceland is monitored daily. The Icelandic Meteorological Office (2020) has a colour coded volcano map, which warns of possible threat to the aviation sector per the recommendations of the International Civil Aviation Organisation. The severities are colour coded from green to red, green meaning that the volcano is in a normal, non-eruptive state and red meaning that an eruption is either forecasted to be imminent or is underway with significant emission of ash into the atmosphere.

The status of Iceland’s Baroarbunga volcano was raised to orange during August of 2014, which had air shippers monitoring the situation closely. The colour code orange means that the volcano is exhibiting heightened unrest with increased likelihood of eruption. At the time, the executive director of the Airforwarders Association, Brandon Fried, stated: “Forwarders and the airlines will likely benefit from lessons learned during the 2010 volcanic eruption that will probably reduce the impact and severity this time.", and also stated that to mitigate and disruption risks, air cargo shippers can route loads in and out of Europe via southern air routes that are outside the potential volcanic plume. (Szakonyi 2014)

Mitigation strategies

The risk mitigation strategies for volcanic activity are selected for a firm to be able to be ready for and to react to a quickly occurring event. Monitoring systems are already developed, and they should be implemented in a firm's supply chain risk management. Other than having ready plans for rerouting shipments, or beforehand avoidance of airspace at risk, not much can be done to limit vulnerability to volcanic activity if a firm is heavily air freight dependent.

Table 13 *Volcanic activity supply chain risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Lower dependency on use of air freight Premade agreements for air freight rerouting possibilities Monitoring and early warning system Clump shipments ahead of and after volcanic eruptions	Make sure supply chain visibility systems are in order during transportation hub shipment build ups Be fast in getting priority shipments, prepare to pay premiums	If essential shipments were majorly delayed, plan for future transport to be possible via alternative transport

4.1.3 Earthquakes and tsunamis

Some of the most disastrous natural disasters are earthquakes and tsunamis. The destruction of structures and loss of life can cause a massive effect on supply chains. The Great East Japan Earthquake in 2011 resulted in a decline in growth rates of the affected areas firm's immediate downstream clients and also propagated to firms which were only indirectly linked to disrupted firms. During the earthquake's and its resulting tsunami's aftermath, individual firms weren't able to insulate themselves from the disruption as they couldn't find alternative sources for their supplies. (Carvalho et al. 2020)

Earthquakes and tsunamis can cause similar disruptions as exceptional weather but are usually more sudden and occur in specific regions more than in others.

Mitigation strategies

Mitigation strategies for earthquakes and tsunamis are listed in Table 14. There weren't many supply chain specific risk mitigation strategies that could be identified in this research.

Table 14 *Earthquakes and tsunamis supply chain risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Assess risk locations using earthquake data and tsunami risk data Practice multi-sourcing from different regions Insurance Implementation of early warning systems	Help local infrastructure repair efforts Assess damage and start repairs Locate shipments	Fix vulnerabilities and re-evaluate suppliers based on disaster response

4.1.4 Diseases

Mid-March the coronavirus had started to spread so rapidly that it was deemed a pandemic by the World Health Organisation (WHO 2020).

The financial market started to decline at the end of February / start of March. One of the first problems concerning logistics was the shortage of empty containers used to ship products due to the build-up of containers at Chinese ports. Passenger flights were also brought to a standstill as social distancing measures were taken in order to slow down the spread of the virus.

Similarities between the supply chain disruptions that the pandemic caused, and disruptions caused by other major events can be found, but the overall effects have been unique. People are spending money more carefully due to the uncertainties surrounding the situation, causing build-up of some non-essential goods, and causing people to stock up on essential items and therefor causing brief shortages.

In Finland, logistics services were identified as essential businesses, meaning that the children of logistics workers could still go to day care as others were forced to stay at home (Hiilamo 2020). This prevented the need for logistics workers to have to stay at home and enabled supply chains to remain in operation.

Air travel took a nose-dive as people started to limit their movement by staying more at home and reducing human-to-human contact (Figure 7). Travel by train was severely impacted with a 90% reduction in trips made by trains, resulting in VR Group in Finland having to resort to temporary lay offs in order to keep costs at minimum. VR also speculated that the metal industry's transports will decrease because the automotive and construction industries have slowed down. (Raidepuolue 2020)

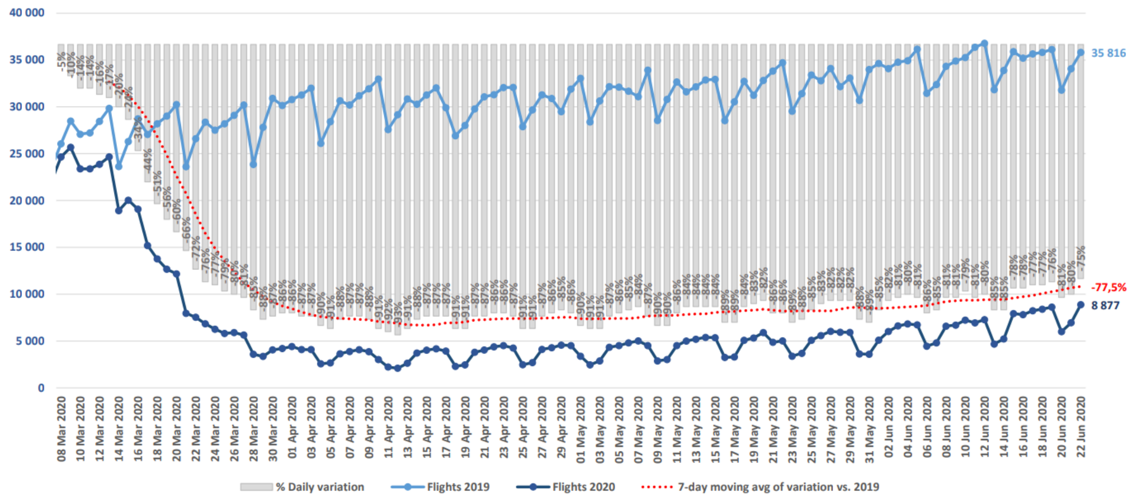


Figure 7 Daily Variation (Flights) compared with equivalent days in 2019 (EUROCONTROL2 2020

The velocity and scale of disruption was unprecedented in 2020. Some supply chains had to halt operations as others had a hard time keeping up with surges in demand. It was clear that supply chains would have to become more resilient in order to survive. BluJay Solutions, Adelante SCM and the Council of Supply Chain Management Professionals (CSCMP) brought forth a research study which revealed how organisations had been able to deal with the pandemic and what they are planning in terms of modifying their supply chains to become more resilient. 75 percent of the 233 qualified supply chain professional respondents claimed that their companies are going to use what they learned during the pandemic as a basis in making changes in their supply chain practices. (BlueJay Solutions 2020)

As Covid-19 caused a need to limit human-to-human contact, several companies were driven to move quickly and unexpectedly to working from home practices. This revealed a lack of efficient HR policies and IT capabilities. For the question of which functions or processes within their supply chain will require the most changes or re-evaluation, 61 percent of respondents ranked IT capabilities and 58 percent human resources in the top two processes in need of change. (BlueJay Solutions 2020)

<u>Mitigation strategies</u>

Frank Straube and Benjamin Nitsche (2020) released an article in which they stated various Covid-19 related disruption mitigation strategies implemented by supply chain experts. The supply chain experts were part of a focus group workshop and consisted of logistics managers from multiple manufacturing industries and logistics service providers. The mitigation strategies will be stated here (Table 10) and used as a guide on how to increase resilience in the final tool which is formed during this thesis.

Table 15 *Short and mid- or long-term strategies dealing with the Coronavirus crisis (Straube and Nitsche 2020)*

	Short-term	Mid & Long-term
Strategy		Decide on level of flexibility in logistics needed (trends towards more supplier and carrier alternatives) Corporate decision on off shoring and nearshoring rates Create synergies in strategic initiatives (e.g. combine network redesign with sustainability initiatives) Decide on the “human factor” in decision making and level of automation
Network	Have trust in network partners, troubleshooting can make it worse Fight for backup supply and transport capacities Increase in safety stock levels if supply is possible Supplier Risk Tower (up to date supplier assessment with vulnerability scores) with automated supplier survey Short-term switch from cost-thinking to availability thinking (taking air freight over other modes of transport) Risk mitigation jointly with third party logistics (3PL)	Enable structural flexibility through multi sourcing (materials & transport capacities) to trend towards more decentralised network structures Reduce network complexity Increased outsourcing of logistics activities (potentials for LSP) Facilitation of nearshoring if possible Turning away from stock-less JIT supply approaches possible
Process	Daily cross-functional crisis team meetings and calls with master planners to develop and implement contingency plans Adjustment of workflows / digitalisation of processes Increased frequency of forecasting and demand planning intervals Reduce lot sizes Defining a catalogue of measures for a safe restart of production and logistics	Establishment of logistics crisis plans and processes for the future
Technology	Learn from crisis data to improve forecasting algorithms	Roll-out of automation approaches to support monitoring and logistics planning (e.g. through multi agent systems) Development of early alert systems following AI approaches
People	Enable home office opportunities Short-time work & reinvented shift-systems Lateral cooperation to increase employee utilisation (e.g. Aldi/McDonalds example)	Interdisciplinary training in companies in order to broaden the areas of application of employees Think about home office as a long-term alternative

The “Lateral cooperation to increase employee utilisation (e.g. Aldi/McDonalds example)” refers to a staff sharing deal between Aldi and McDonalds, where employees of McDonalds were allowed to “quickly and unbureaucratically” switch to working at Aldi. Aldi was facing a surge in demand and McDonalds faced restaurant related restrictions in March, 2020. (Springer 2020)

Some of the strategies listed in Table 15 are strategies which specifically target the decrease of disease transmission and others are useful in all major disruptions. For instance, a supplier risk tower with up to date supplier assessments and vulnerability scores is an overall great tool to use in preventing adverse effects to supply chains. Reorganising mitigation strategies into the three periods of time: before, during and after a crisis and choosing the most appropriate strategies for disease caused disruptions for this tool, we come up with the strategies in Table 16.

Table 16 *Diseases supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Corporate decision on off shoring and nearshoring rates Establishment of pandemic crisis plans and processes Train for the implementation of disease related risk mitigation strategies	Increase frequency of forecasting and demand planning intervals Gather data for future use Trust network partners, troubleshooting may have adverse effects	Use data gathered during the pandemic to improve forecasting algorithms Review strengths and weaknesses of disruption response

Plan for and routinely execute work-at-home opportunities Make plans for shorter or otherwise restructured work shifts Plan for and execute automation approaches	Short-term switch from cost-thinking to availability-thinking Now at latest roll-out automation approaches Frequent meetings with supply chain partners to determine the newest developments	For costs savings, renegotiate costly contracts made during the pandemic

4.2 Political and legal instability

4.2.1 Terrorism and war

More on the extreme side of disruptive events are terrorism and war. Both include the threat of violence and they both hinder the normal flow of supply chain operations. Historically, the 9/11 attacks were the first major terrorist attack to start a new era of security checks at airports. Shutting down air traffic immediately after the attacks caused delays in shipments. Future disruptions caused by terrorism and war may be the loss of airports or shipping yards due to attacks or occupations, or loss of supply chain links at sea or airspace due to war.

When USA invaded Iraq, there was a slight disruption in air cargo capacity. The fact that airlines started to fly around airspace in the Middle East, meant that more fuel was consumed and it resulted in the need to lower cargo capacity. (Craighead et al. 2007)

One of the most inefficient supply chains of modern times was created in Palestine, caused by the Israeli assault on Palestine's logistics infrastructure. The flow of goods was disrupted by checkpoints, closures, militarised border crossings and other physical borders. The result was Palestine lacking a seaport, airport and a viable rail system, which caused a great reliance on trucks for supply. (Alimahomed-Wilson and Ness 2018)

Mitigation strategies

Mitigating risk of terrorism and war is contextual, as smaller armed conflicts, terrorist attacks and full out wars all carry out varying effects. They all however require swift action and insurances can be bought to mitigated risk. The identified risk mitigation strategies are listed in Table 17.

Table 17 *Terrorism and war supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Set up system that monitors political unrest and international conflicts Plan for fast evacuations from risk areas Apply for security certificates such as AEO Empower local operators in order for them to be able to make quick decisions Insurance	Evacuate personnel from active war zone Work with government to determine best course of action Set up new site for operations Work to secure lost assets	Make sure situation has settled before continuing operations in affected areas

4.2.2 Economic conflicts

Economic conflicts, in the scope of this thesis, are trade wars and disputes, where trade barriers such as tariffs and embargoes are issued between countries or unions. Brexit and the USA – China trade war are examples of ongoing economic conflicts.

The United States and China engaged in a trade war, as both countries raised tariffs on a list of goods. It has caused disruptions in supply chains and has led to many businesses to move manufacturing to third-party countries, such as Vietnam, to avoid the increase of tariffs on both sides. The rethinking of country of origin became important on products as it is usually the basis on which tariffs are determined. In some cases, the last step of a products manufacturing, assembly of a product, can be the determining factor to state the country of origin. (Yang 2019)

Mitigation strategies

The risk mitigation strategies identified from case studies are listed in Table 18.

Table 18 *Economic conflicts supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Try to stay out of countries where major political uncertainty exists (especially if your product is the first to be put on the embargo or sanctions list) Leverage supply chain visibility to run scenarios based on possible future tariff changes Country of origin data to be included in supply chain visibility applications	Update forecasting based on new prices Update your product pricing Near shoring approaches if new pricing allows / integrate with sustainability programs Constant monitoring to identify new additional tariffs	Be considerate of possible price fluctuations based on previous experience Re-assess product pricing Sourcing optimisation review

	Shifts in product assemblies to change country of origin	

4.3 National economic and financial instability

4.3.1 Financial crises

In 2008 and 2009, a financial crisis led to an increase in corporate insolvencies with a record amount of high-profile insolvencies and bankruptcies. The crisis affected nearly all regions and industries in some way, thus proving the necessity of crisis risk management. (Blome and Schoenherr 2011) Reviewing financial crises which happened before 2008 may be somewhat in vain, given that the global market has made a huge change in the near decades.

Blome and Schoenherr (2011) stated that a financial crisis is different from a single supplier failing to fulfil an obligation, as the entire supply chain network, focal firm included, may be under distress. They also make the observation that a financial crisis doesn't necessarily only cause negative impacts, but may also lead to some positive outcomes, e.g. suppliers having idle capacity which could result in shorter lead times, having a positive effect on the buying firm. They noted in their study that all their sample firms felt that especially supplier insolvencies had caused the increase of awareness of supply chain risks.

The 2008 financial crises had a varying effect on SCRM through different industries and firms. The most obvious effects where the changes it caused in the automotive industry, in which teams, processes and information technology tools have been developed to help with SCRM. The automotive industry was also heavily impacted by the high number of supplier insolvencies and was simultaneously impacted by supply and demand. The crisis dramatically increased the need for SCRM in the fashion industry, where suppliers are mainly located in Asia. (Blome and Schoenherr 2011)

Mitigation strategies

Mitigation of financial crises caused disruptions is done by tracking supply chain finances and keeping them in order. Not only must your own firm's finances be in order, but also your suppliers', shippers' and clients'. The few identified mitigation strategies are listed in Table 19.

Table 19 *Financial crises supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Keep track of finances concerning your suppliers, your costumers and your own Keep a healthy reserve of money Maintain an essential low-cost product which people need even when not spending money on nearly anything	Possibly offer financial aid to your shippers/3PL-firms in order to secure future shipments	Build up reserves in the long run

4.3.2 Labour strikes

Strike action may cause a massive and long-lasting disruption in supply chains if a large labour union is involved and negotiations stretch on. The disruption is especially harmful in ocean freight if longshoremen strike, as containers may be stuck in shipping yards and ships, and there may be no alternative transportation mode for large and bulk shipments.

Negotiations themselves may have an adverse effect on supply chains even if a strike never happens. Due to the risk of a supply chain disruption occurring, retailers can increase their shipments sizes to prepare for a possible halt in supply. The increase in shipments during a negotiation disrupts the normal flow of cargo resulting in slowdowns. (LEGACY 2014)

Some of the issues, for which strike action is taken, are workers wanting higher wages, bonuses, benefits, longer breaks, long term work schedules and altogether better working conditions. (Alimahomed-Wilson and Ness 2018) Labour strikes can emerge in several parts of a firm’s supply chain, from warehouse workers to upper management. Interorganisational communication, fairness and common goals are important to maintain so that disruptions are minimised.

<u>Mitigation strategies</u>

Strike action can usually be avoided by paying attention and paying a fair salary. Even if a strike occurs, it can usually be dealt with using money. Having a stable financial situation in your firm goes a long way in mitigating the risks of labour strikes. The mitigation strategies for labour strikes are in Table 20.

Table 20 *Labour strikes supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Work with unions in order to make sure your firm is in compliance with union regulations Keep your own workforce satisfied Make plans for transportation type replacement Automation of processes to limit dependency on employees Fast training programs for the hiring of new employees and well documented procedures for handling day-to-day processes	Locate shipments to extract them from places where strikes are ongoing e.g. out of container yards etc. in order to start rerouting	Make sure employees are pleased with the new terms Maintain constant communication with labour unions and employees

4.4 General disruption supply chain risk mitigation strategies

The remaining risk mitigation strategies, which were seen as suited to be used in all of the disruptive events are listed in Table 21. Some of them are straight from existing literature (Straube and Nitsche 2020) and some of them were identified from case studies.

Table 21 *General supply chain disruption risk mitigation strategies*

Before a crisis	During a crisis	After a crisis
Invest in Business Continuity Planning (BCP) and Disaster Recovery (DR) Turn away from stock-less JIT supply approaches as possible Facilitate nearshoring as possible Reduce network complexity Create synergies in strategic initiatives (e.g. combine network redesign with sustainability initiatives) Add structural flexibility by multi sourcing (keep the same essential supplies flowing from several sources and via different transport) Maintain a good reputation in the business field	Negotiate for alternative supply and transport capacities fast Have trust in network partners as troubleshooting can make matters worse Document strengths and shortcomings on managing the disruption Gather data on inbound and outbound logistics Short-term switch from cost-thinking to availability-thinking Increase frequency of forecasting and demand planning intervals /switch to disruption time forecasting	Roll back measures taken during the crisis in order to gain profitability Possibly leave some measures as future redundancies Re-evaluate business continuity plans Gain good relationships with supply chain partners Try to assess where the greatest risk is in your post disaster situation

Get rid of unnecessary legacy processes which can be replaced by digitalisation		

5. CREATING THE SUPPLY CHAIN DISRUPTION PREPAREDNESS SCORECARD

The creation of a supply chain disruption preparedness scorecard for the use of businesses has the challenge of creating one which is useful and contextual in most situations. The ability to be able to modify scorecards is essential to match the industry specifics. The focus of this disruption preparedness scorecard will be on major disruptions caused by crises and other catastrophic events. Disruption preparedness is defined in this thesis as the ability to prevent the effects of disruptions as well as to be able to continue operations as fast as possible after a major disruption. More often occurring smaller disruptions, such as small labour strikes, slight shifts in demand and manufacturing errors, will be left out of the equations.

Lean principles, such as not having to enter the same data twice (using a single input for several outcomes) and avoiding waste (collection of unnecessary data) in the process of filling the form, will also be applied.

Because the sources of environmental and institutional volatility arrive from sources exogenous from the focal firm's own daily practices, some data for the volatility assessment will also be pulled from various outer sources. For example, the risk involved with sourcing supply from the hurricane region of The United States of America could be evaluated with the combination of hurricane frequency data and region specific political and financial risk assessments.

The most used evaluation method will be rating scales. Having to evaluate statements on a scale will make answering faster, as there are several measures to evaluate, and the idea of the tool is to give a quick estimate opposed to a more in-depth analysis. A more structured approach could be taken with the input of financial data, lead times etc., but all firms do not collect the same types of data, so a statement – response model will suffice.

5.1 Transportation measures

Having some measures that assess the modes of transport is necessary to be able to estimate weaknesses to some major disruptions which primarily affect only a few transportation types e.g. the availability of road transportation suffered minimally from the Covid-19 pandemic. The aim is to be able to determine how dependent the focal firm is on each transportation method and ultimately use that to assess the possible impact of losing the ability to use individual methods.

The measures with transportation in Table 22 evaluate the importance of different modes of transportation: marine, air, road and rail. A value per shipment approach could be taken to determine a value percentage for all modes of transportation if a more thorough analysis were needed, but to keep the this form simple, a rating scale will be used. In the rating scale 0=not important at all, 1/6=not important, 2/6=slightly not important, 3/6=neutral, 4/6=slightly important, 5/6=important and 1=extremely important.

Table 22 *Transportation measures*

Variable	**Statement**	**Scale**
TM_1	How important are marine functions to your business?	[0Not important at all;1Extremely important]
TM_2	How important is the operation of air transport to your business?	[0Not important at all;1Extremely important]
TM_3	How important is road cargo to your business?	[0Not important at all;1Extremely important]
TM_4	How important is the operation of rail transport to your business?	[0Not important at all;1Extremely important]

Ranking the importance of transportation methods on a seven-point rating scale should prove significantly faster than calculating the actual share and value of each method. Other measures regarding transportation methods could be the evaluation of how easy it would be to switch to an alternative transportation method, e.g. a longshoremen strike resulting in the need to switch from maritime to air transport. The evaluation of the importance of transportation of different modes of transportation should however take this aspect into account adequately.

5.2 Supplier related measures

Suppliers are in a key position when major disruptions occur. They have to remain in operation and fulfil orders in order to keep the supply chain flowing. Close collaboration and active monitoring are needed in order to have a reactive supply chain.

The identified measures involved with suppliers (Table 23) are ones related to the performance of the suppliers and the performance of the cooperation of the focal firm and their suppliers. The measures are evaluated by using a 7-point Likert-scale from here on out, where In the rating scale 0=strongly disagree, 1/6=disagree, 2/6=somewhat disagree, 3/6=neutral, 4/6=somewhat agree, 5/6=agree and 1=strongly agree.

Table 23 *Supplier related measures*

Variable	**Statement**	**Scale**
SM_1	Our supplier performance measurement system is functional and effective.	[0Strongly disagree;1Strongly agree]
SM_2	We track our suppliers' finances.	[0Strongly disagree;1Strongly agree]
SM_3	We work together with our suppliers to ensure performance and continuity.	[0Strongly disagree;1Strongly agree]
SM_4	Our suppliers are flexible, they can deliver smaller or larger batches on short order.	[0Strongly disagree;1Strongly agree]
SM_5	Our supply chain visibility is excellent, and we know where, and in what process, every moving part is at all times. (Upstream, downstream, suppliers' suppliers etc.)	[0Strongly disagree;1Strongly agree]

The measures were chosen for their usability in determining the aspects of suppliers which correlate to major disruption preparedness. Supply chain visibility, flexibility, cooperation, steady finances and performance are all important characteristics in the reactive side of dealing with major disruptions.

5.3 Essential locations

Risk associated with a specific country will be implemented in the assessment tool, where one country could be prone to disruptions caused by environmental events and another one could be vulnerable to political unrest.

The task will be to name countries which are essential to the focal firm's operations. The limit on the number of countries will be 10, to limit time spent on filling the tool. Gathering a list of essential countries will be one of the most important parts of the disruption preparedness scorecard, because, as said, most major disruptions are area specific.

Choosing the most essential locations for the focal firms' operations will give a data output equivalent of "yes, this country is important" or "no, this county is not important". Having just two alternatives may result in a too polarized result for the assessment, but it does have the upside of saving a huge amount of time compared to an approach where the scale of importance of each country would have to be determined.

5.4 Business continuity planning measures

Business continuity planning and disaster recovery are important processes considering major disruptions. Being able to minimize the impact of major disruptions is essential for disruption preparedness, and business continuity planning offers many measures to choose from.

The measures in Table 24 were chosen to represent the business continuity planning measures that are supply chain related as well as usable in determining preparedness for the possible major disruptions which were identified earlier.

Table 24 *Business continuity planning measures*

Variable	**Statement**	**Scale**
$BCPM_1$	We have a functional business continuity plan.	[0Strongly disagree;1Strongly agree]
$BCPM_2$	Our organization has trained for the possible activation of our business continuity plan.	[0Strongly disagree;1Strongly agree]
$BCPM_3$	We have plans in place to be able to switch to an alternative supplier for our critical supplies.	[0Strongly disagree;1Strongly agree]
$BCPM_4$	We are prepared to work from an alternative workspace.	[0Strongly disagree;1Strongly agree]
$BCPM_5$	All of our essential data is backed up.	[0Strongly disagree;1Strongly agree]

There are a lot more business continuity planning measures which could have been included, but with the aim at keeping the overall disruption preparedness assessment short, only the most valuable measures, which most precisely mitigate institutional and environmental volatility are included. $BCPM_{1-2}$ are chosen to represent general disruption preparedness, $BCPM_3$ for disruptions where supply from a distinct location has been cut off, $BCPM_4$ for the loss of production/management sites or ability to be present and $BCPM_5$ for disruptions where power outages occur.

5.5 Operations measures

The way the focal firm operates determines a huge portion of the effects which will be faced after a disastrous event. Key aspects, which will be important in the assessment of disease caused disruption resilience and general disruption preparedness, will be determined by the four operations related measures in Table 25.

Table 25 *Operations measures*

Variable	**Statement**	**Scale**
OM_1	We are able to conduct our business so that human-to-human contact can be eliminated.	[0Strongly disagree;1Strongly agree]
OM_2	Our operations are highly automated.	[0Strongly disagree;1Strongly agree]
OM_3	We haven't fully adopted Just-in-time principles and still maintain a moderate safety stock.	[0Strongly disagree;1Strongly agree]
OM_4	We have eliminated the need for paper, everything is digital.	[0Strongly disagree;1Strongly agree]

Again, there is an infinite amount of measures which determine the focal firms' operations, but only a finite amount of time is available for the assessment. The selected measures closely correlate with successes and failures of past handlings of major disruptions e.g. the drive for full digitalisation to replace paper-based processes has been on-going for long but expedited due to Covid-19. (Pope 2020) The need to handle process changes during a disruption is an extra task which would be easier to handle during stable times.

6. VALUATING AND OPTIMIZING PREPAREDNESS

The results of the gathered measures have to be processed so that they can give an assessment of the current state of disruption preparedness. The scorecard will feature the supply chain volatility dimension of institutional and environmental volatility, first divided into the meta-sources: national economic and financial instability, political and legal instability and exceptional environmental events, then their meta-meta-sources depicted in Chapter 4.

Distributing the collected data to match the identified disruptions and the weighting of the different measures were done by first self-estimating, followed by unstructured discussions with fellow researchers.

6.1 Exceptional environmental events

Extreme weather

The needed extreme weather data was collected from the Global climate risk index 2020, where storms, floods, temperature extremes and temperature mass movements were incorporated into a worldwide analysis. Their data was based on the work done by the Germany based re-insurance company Munich Re. The Global climate risk index 2020 fortunately left out geological events, such as earthquakes, tsunamis and volcanic activity, as they are not reliable on the weather. (Eckstein et al. 2019)

The indicators which were analysed are: number of deaths, number of deaths per 100 000 inhabitants, sum of losses in US$ in purchasing power parity and losses per unit of gross domestic product. The index score CRI is calculated by weighting the ranks of each country in each category: 1/6 for the death toll, 1/6 for the absolute losses in purchasing power parity, 1/3 for deaths per 100 000 inhabitants and 1/3 for losses per unit of gross domestic product. (Eckstein et al. 2019) The CRI score for 1999-2018 was used in the disruption preparedness scorecard to give a more refined score than that of using just the yearly score of the year 2018.

The extreme weather supply chain disruption preparedness EWDP is calculated by:

$$EWDP = \left(\left(1 - \frac{\widetilde{CRI}}{188}\right) * \frac{3}{10} + \left(1 - \widetilde{TM}_{1-4}\right) * \frac{4}{10} + GDP * \frac{3}{10}\right) * 100\%$$

where $\widetilde{TM}_{1-4}$ is the arithmetic mean of the transportation measures and $\widetilde{CRI}$ the mean of the selected countries' climate risk index rank among 188 countries. $\widetilde{CRI}$ is divided by the number of countries in the ranking which runs from worst to best. GDP is the general disruption preparedness which is formulated by:

$$GDP = \widetilde{SM}_{1-5} + \widetilde{BCPM}_{1-5} + OM_3$$

where $\widetilde{SM}_{1-5}$ is the mean of the supplier related measures and $\widetilde{BCPM}_{1-5}$ is the mean of all the business continuity planning measures. These, and OM_3, are general measures which help evaluate supply chain disruption preparedness in most situations and are therefor incorporated, in a varying degree, in all the following equations.

The weighting here follows an approach where 30% of the score comes from pure location-based risk exposure. A 40% weight is placed on the dependency of each transportation method, and the last 30% is placed on the combative measures in GDP.

The weighting of the measures doesn't have to be dead-on for the tool to work and thus the method of creating them isn't structured. The focus is on having all the appropriate measures included so that changes in their values can be seen in the final result. Users of the tool are also free to change weightings as they see fit.

Volcanic activity

Reliable data for the risk of volcanic ash clouds could not be procured and even if the data could be found, using that data to assess a country's supply chain disruption risk could prove difficult as volcanic ash prevents the use of air transportation routes as well as the use of airports.

The exposure is instead taken into account only by the stated dependency of air transportation. There also aren't any specific measures that were collected to be used for the assessment of volcanic activity caused disruption preparedness, so the reactive side of the preparedness assessment is evaluated by using GDP:

$$EWDP = \left(\frac{TM_2}{6} * \frac{5}{10} + GDP * \frac{5}{10}\right) * 100\%$$

The weighting is done by placing half the value on the risk exposure side and half on the reactive capabilities.

Earthquakes and tsunamis

The selected earthquake data is in the form of country specific exposure measures derived by Lackner (2018). Lackner refined earthquake shaking data from USGS Shakemaps to the measure "Exposure 2B", which contains the number of strong events across the spatial average of the high exposure area. The values of the measure range from 0 (best) to 2.5 (worst) and will thus have to be divided by 2,5 to modify them for the wanted result. The earthquakes and tsunamis supply chain disruption preparedness is calculated by:

$$ETDP = \left(\left(1 - \frac{\widetilde{EQ}}{2.5}\right) * \frac{4}{10} + (1 - (TM_1) * \frac{2}{10} + \left(1 - (\widetilde{TM}_{2-3}\right) * \frac{1}{10} + GDP * \frac{3}{10}\right) * 100\%$$

The weighting is formed to include a 40% weight on the location-based side, 20% on marine traffic (higher than other modes due to tsunami risk), a combined 10% on rail and road transportation and the final 30% on GDP.

Diseases

A way of linking the efficiency of supply chains based on a country's perceived ability to deal with a pandemic could not be figured out in the scope of this thesis. Therefor a location-based assessment is replaced with a transportation type dependency assessment. Air transportation and marine transportation were the most severely affected transportation types and they will be included in the assessment.

The diseases supply chain disruption preparedness is calculated by:

$$DDP = \left(\left(1 - \widetilde{TM}_{1-2}\right) * \frac{4}{10} + \widetilde{BCPM}_{3-4} * \frac{2}{10} + \widetilde{OM}_{1-2} * \frac{2}{10} + GDP * \frac{2}{10}\right) * 100\%$$

An extra emphasis is placed on the business continuity planning measures which were included in the self-assessment stage primarily with disease resilience in mind. Again, about half the weight is placed on the exposure side, which in this case is the transportation method side. The remainder of the weighting is placed on the resilience side.

Total score for exceptional environmental events supply chain disruption preparedness

The mean of the previous scores of extreme weather, volcanic activity, earthquakes and tsunamis, and diseases will state the total score for exceptional environmental events supply chain disruption preparedness (EEDP).

$$EEDP = \frac{EW + VA + EQ + D}{4}$$

By altering the equation, it is easy to tailor the tool for varying supply chains. For example, for a supply chain which is known to not face any risk from volcanic activity, VA could be removed from the EWDP calculation.

6.2 Political and legal instability

Terrorism and war

Country specific data on the perceptions of the likelihood of political and/or politically motivated violence from The World Bank's Worldwide Governance Indicators is used in determining exposure to risk involved with terrorism and war. The data provides a yearly snapshot of the perceived threat levels by combining the views of enterprise, citizen and expert survey respondents.

The Worldwide Governance Indicators data accuracy has been questioned by several researchers and defended by the authors. Critique is placed on aspects such as using different data sources to produce data for different countries, losing comparability. (Kaufmann, Kraay, and Mastruzzi 2007) However, the data is sufficient for the scope of this thesis, as a more structured and as vast dataset could not be found.

The terrorism and war supply chain disruption preparedness (TWDP) is calculated by:

$$TWDP = \left(\left(1 - \frac{(\widetilde{PS + 2}.5)}{5} \right) * \frac{4}{10} + (1 - TM_2) * \frac{2}{10} + GDP * \frac{4}{10} \right) * 100\%$$

Extra emphasis is placed on the dependency of air transportation on the reactive side, as historical events have proven air traffic to take an early hit when faced with threat (Brauer and Dunne 2012).

Economic conflicts

Economic conflicts, including trade wars, economic sanctions and embargoes, will be evaluated by using AM Best's political (PR) and economic (ER) risk ratings. AM Best's economic risk score is based on "... the state of domestic economy, government finances, and international transactions, as well as prospects for growth and stability.", and political risk "... comprises the stability of the government and society, the effectiveness of international diplomatic relationships, the reliability and integrity of the legal system and of the business infrastructure, the efficiency of the government bureaucracy, and the appropriateness and effectiveness of the government's economic policies.".(AM Best 2020)

As can be seen, the most decisive attributes of economic conflicts form only a part of the full risk ratings. However, in lack of a more precise country specific risk assessment, combining the two previously mentioned AM Best's categories of risk will suffice, as they include the evaluation of international transactions and the effectiveness of international diplomatic relationships, which are key factors in economic conflicts. The evaluation isn't ideal, as sanctions can be applied by a league of nations (e.g. EU sanctions on Russia) instead of just one specific country.

The economic conflicts supply chain disruption preparedness (ECDP) is calculated by:

$$ECDP = \left(\frac{PR + FSR}{10} * \frac{4}{10} + \left(\frac{BCMP_3 + SM_4}{2}\right) * \frac{2}{10} + GDP * \frac{4}{10}\right) * 100\%$$

Here, the country specific data forms 40% of ECDP, as location is the basis of international economic conflicts. Another strong factor is the dependency of a single supplier in a specific country, so the ability or inability to change suppliers ($BCMP_3$) and shipment sizes (SM_4) will be highlighted by giving those measures an extra 20% weight. The rest is composed by the GDP.

Total score for political and legal instability supply chain disruption preparedness

The average of TWDP and ECDP is calculated to form the total score for political and legal instability supply chain disruption preparedness (PLIDP):

$$PLIDP = \frac{TWDP + ECDP}{2}$$

6.3 National economic and financial instability

Financial crises

The data used for location-based risk will be AM Best's Financial System Risk from their Country Risk Reports. The risk category is stated to include the risk of financial volatility erupting due to a weak banking system, weak asset markets and a poor regulatory structure. (AM Best 2020)

The financial crises supply chain disruption preparedness (EWDP) is calculated by:

$$EWDP = \left(\frac{FR}{5} * \frac{4}{10} + SM_2 + SM_4 + BCMP_3 * \frac{4}{10} + GDP * \frac{2}{10}\right) * 100\%$$

About half of the preparedness score comes from the vulnerability of location and state of monitoring systems. The rest is formed of the ability to overcome a financial crisis with general methods and an emphasis is placed on the ability to switch suppliers and alter shipment sizes.

Labour strikes

The likelihood of facing disruptions caused by massive labour strikes should be evaluated by using data on the probabilities of strike action in varying industries and in different countries. As the gathered survey data doesn't include industry classification, the evaluation could be based on the dependency of different transportation types and essential countries. However, lacking data of strike action risk sectioned by risk per transportation method could not be found.

The preparedness evaluation will therefor be based solely on essential countries, on the risk side. Data on the likelihood of labour strikes in specific countries will be based on AM Best's evaluation on labour flexibility. Their definition for labour flexibility is that it measures the flexibility of the labour market and includes a company's ability to hire and fire employees. (AM Best 2020) Not precisely a strike action risk evaluation, but inflexibility in labour does offer great grounds on which to insinuate a strike.

The labour strikes supply chain disruption preparedness (LSDP) is calculated by:

$$LSDP = \left(\frac{LF}{5} * \frac{4}{10} + \frac{SM_3 + OM_2}{2} * \frac{2}{10} + GDP * \frac{4}{10}\right) * 100\%$$

About half of the weight is placed on liability and half on the ability to overcome the adverse impacts of strike action.

<u>Total score for national economic and financial instability supply chain disruption preparedness</u>

The average of FCDP and LSDP is calculated to form the total score for national economic and financial instability supply chain disruption preparedness NEFIDP

$$NEFIDP = \frac{FCDP + LSDP}{2}$$

6.4 Total score for institutional and environmental disruption preparedness

The thee meta-sources are compiled together to form the total institutional and environmental disruption preparedness (IEDP) score of

$$IEDP = \frac{NEFIDP + PLIDP + EEDP}{3}$$

Here weights should be added to individual meta-sources in order to fit a specific supply chain.

7. CONCLUSIONS AND DISCUSSION

This thesis set out with the task of solving a lack of preparedness in face of supply chain disruptions caused by various major large-scale events. The focus was on events which occur seldom, but ones which have a massive adverse effect on the functions of supply chains when they do occur.

The supply chain volatility dimensions proposed by Nitsche & Durach (2018) helped organise disruption causes, which were identified from studies, into the three meta-sources of institutional and environmental volatility: national economic and financial instability, political and legal instability and exceptional environmental events. Sorting the identified major disruption causes into the meta-sources wasn't clear regarding diseases and some disruptions which were left out of this thesis e.g. cyber attacks or sudden loss of IT-capabilities, as they don't have a clear slot to fall into, and thus the meta-sources could be reconsidered on behalf of institutional and environmental volatility to include communication breakdowns and spread of disease prevention measures.

The identified historical 'black swan events' and near past major disruption causing events were derived at by extensively studying supply chain disruptions. At this point it was realised that the scope of this thesis wouldn't allow for a perfectly thorough study on all of the aspects of preparing for a major disruption.

A tool aimed at increasing preparedness for these types of events had to incorporate a way of measuring a firm's inner workings in order to be able to estimate how well it is suited to face a disruption. The disruption types had to be identified and equations had to be developed in order to be able to evaluate preparedness for each cause of disruption. Lastly, it seemed crucial to include an action list of mitigation strategies for each type of disruption, so that the tool could serve as a comprehensive way of solving the original problem of increasing preparedness in face of supply chain disruptions caused by various large-scale events.

The method of identifying and selecting measures was quite vague. The lack of research on the specific topic of how to measure the capacity of preparedness for major supply chain disruptions didn't allow for a more structured approach.

Disruptions were analysed, and the core characteristics of supply chains were estimated based on location and by using rating scales. If this thesis were to be replicated, one could arrive at a different set of measures and evaluations. As it became apparent that the tool would serve more as an infrequently used tool, opposed to a continuous tool, the measures were chosen to be mostly self estimated in order to reduce time spent filling the form. The measures are the part which should be first altered if a continuous measurement tool were to be formed.

Location based risk evaluations formed a huge part of the work done towards this thesis. Finding evaluations which were well founded and fit the specific risk types was a time-consuming task, but it succeeded fairly well, although it was chosen that several countries were to be left out of the tool due to not having data on all of them. Still, 116 countries remained which all had evaluations on the risks which could be used in the disruption preparedness equations.

Another key part in any future development of this tool would be to make sure that the collected datasets are up to date and accurate. With the arguably too outdated dataset used in this thesis, the preparedness tool mainly offers an answer to the question: “Can a major supply chain disruption preparedness tool be formed?”, instead of providing a perfectly working one.

The forming of the equations used to determine the disruption preparedness scores was developed without a strict framework, as it was deduced that for this kind of overview and guidance tool it wasn’t needed to have a perfectly balanced set of scores. Disruption ‘preparedness’ was viewed in this thesis to be a combination of risk exposure and the ability to overcome a possible disruption. With that in mind, the equations were formed to have half the weight on risk exposure and half on the supply chain’s resilience on a scale of 0 to 100%.

Risk mitigation strategies were sought out from existing literature, but the only extensive study was found on the Covid-19 supply chain disruption. Other mitigation strategies had to be formed based on what was learned studying the various disruption types.

With this last part finished, the main goal of the thesis was successfully accomplished. This thesis is, considering all the material which was found during the completion of this thesis, a first of it’s kind comprehensive tool for assessing preparedness and guiding supply chain development in face of institutional and environmental volatility.

The terminology involved with managing risks where seldom occurring massively impacting events are involved should be further developed. In some ways, the volatility management, supply chain continuity planning, supply chain resilience and supply chain risk management all overlap. A clear set of definitions for what is counted as a major disruption in each event category would also be helpful e.g. how strong of an earthquake.

The ongoing Covid-19 crisis has for sure had a huge impact on how people have started to view supply chain disruptions. Not being able to get commodities led to vast media coverage on the disruption of supply chains. Now, over a year after the pandemic started, supply chains have adapted and overcame the initial impact. The inertia of having a steadily flowing supply chain in stable times could be reduced to combat vulnerability. Almost all of the risk mitigation strategies cost money. Having enough redundancies effectively eliminates risks. Planning for disruptions also costs money, which could be the cause of firms being so susceptible to disruptions. It should however be noted that the loss of revenue during a disruption may even cause bankruptcy. Investing in risk management could be a financially viable option as Figure 8 (Sodhi and Chopra 2014) suggests.

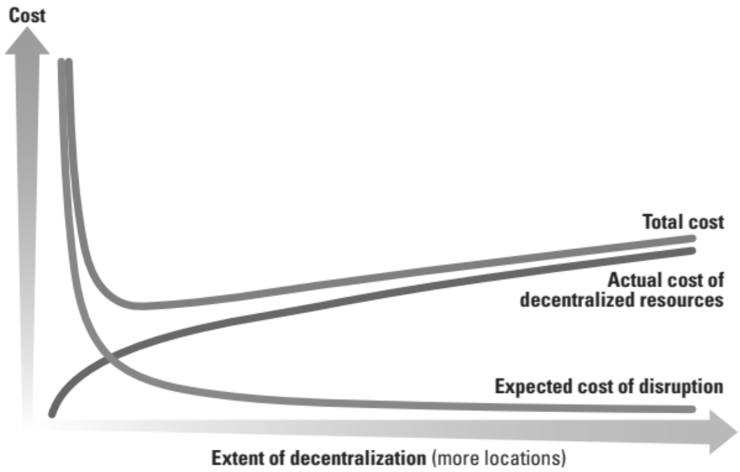


Figure 8 *Cost of redundancies (Sodhi and Chopra 2014)*

Future studies on the topic could include a comprehensive study on each event type's risk mitigation strategies and passive and active measures which correlate to disruption preparedness. 'Black swan' events could also be speculated on further e.g. provide action lists on what to do if sea levels rise suddenly. Looking back, cyber attacks should have been included in this thesis, but were left out due to the excessive workload from analysing the already identified disruption causes.

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