Disruptive Risk Reduction Mitigation Strategies of First-Tier Automotive Suppliers

An analysis of the ramifications of supply chain risk mitigation strategies used against disruptive events, particularly COVID-19, within global first-tier automotive suppliers.

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Dedication

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Abstract

COVID-19 caused disruptions within the global supply chain of every industry. The automotive industry was no exception due to the high complexity of their supply chains, with supply, demand and operational risks increasing dramatically. First-tier automotive suppliers had to shut down their plants during lockdowns, demand for electronic products rose, while side disruptions, such as a semiconductor shortage, caused supply chain disruptions. Supply chain risk mitigation strategies have been implemented by managers to help keep firms' resource capabilities viable.

The disruptions caused within the supply chain of first-tier automotive manufacturers were analyzed to find how supply chain risks, such as the bullwhip and ripple effects, threatened the viability of firms. In this thesis, risk mitigation strategies were scrutinized to find how they impacted the operational capabilities of these firms.

To investigate how risk mitigation strategies have affected firms' operational capabilities, a literature review was first analyzed and written. Afterwards, in a multiple case study, seven interviews with eight key players were conducted to investigate how COVID-19, and other disruptions, affected first-tier suppliers. The interviewees also highlighted how risk mitigation strategies were implemented to fight such disruptive events.

As part of this research, this study identified that the most effective proactive strategy is a forecasting model, with the use of a digital twin and R&D investments in artificial intelligence, while three reactive strategies were found: 1. strategic multiple supplier strategy, both regional and global, 2. some safety stocks of critical parts, and 3. a crisis team prepared for any sort of disruptive event. A balance of cost and risk is the most important decision-making aspect to a proper risk mitigation strategy mix.

The entire industry is undergoing a massive change towards autonomous and electric vehicles with the increased use of artificial intelligence and other technological advancements in risk mitigation strategies.

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List of Abbreviations

AI	Artificial Intelligence
BIM	Building Information Models
CA	California
CCMT	Corporate Crisis Management Team
Doi	Digital object identifier
DE	Deutschland *(Germany)*
Dr.	Doctor
Eds.	Editors
et. al.,	Et alia *(and others)*
IoT	Internet of Things
ISN	Intertwined Supply Network
JIT	Just-in-Time
LCD	Liquid Crystal Display
MI	Michigan
NY	New York
OEM	Original Equipment Manufacturer
PO	Purchasing Order
QDA	Quantitative Data Analysis
RFID	Radio Frequency Identification
RBV	Resource Based View
SC	Supply Chain
SCRM	Supply Chain Risk Management
US	United States
VSC	Viable Supply Chain
VW	Volkswagen

1. Introduction

This thesis starts with an explanation of the problems found within first-tier automotive suppliers, the research questions looking to be answered and a brief overview of the structure of this thesis.

1.1. Problem Statement

Disruptive risks along the global Supply Chain (SC) are a common problem for manufacturing firms that researchers have been trying to solve through various risk mitigation strategies (Srivastava & Rogers, 2021, p. 2; Blos, Quaddus, Wee, & Watanabe, 2009, p. 247). Now, in the midst of a global pandemic, risks have risen and manufacturing industries have suffered financial and operational losses due to disruptions along the SC. Disruptions included the closure of plants, resulting in the loss of production due to COVID outbreaks among the workforce, as well as border closures halting transportation of supplies. In order for a firm to remain profitable it needs to be viable, so that the firm is able to get through a major long-term disruption along the SC by re-structuring its economic performance (Ivanov, 2018, p. 59).

One major problem that researchers have not analyzed yet, due to the freshness of the situation, is what kind of negative impacts COVID-19 had within first-tier automotive suppliers' SCs and their effects on their operational capabilities. This problem has led to a dilemma. The dilemma, in this case, is the effectiveness of risk mitigation strategies used in avoiding major resource losses due the negative impacts of COVID-19.

The findings in this thesis, found in §5, give an overview of how supply chains of first-tier automotive suppliers are structured in current times, indicate how the pandemic affected these types of firms and show which risk mitigation strategies were implemented. Through this information, it is found how first-tier suppliers are currently doing based on their mitigation strategies and what is predicted to happen to such supply chains after the pandemic ends.

First-tier automotive suppliers were not exempt from the economic downturn of 2020. First-tier automotive suppliers supply Original Equipment suppliers (OEMs) with components that the OEMs cannot viably make with their limited resources. These suppliers are usually found near the middle of the SC (Messina, Santos, Barros, & Matopolous, 2015, p. 2).

The automotive industry, including first-tier suppliers, has an extremely large impact on the global economic market. In 1991, for example, the auto industry employed over 8% of American manufacturing workers (Childerhouse, Hermiz, Mason-Jones, Popp, & Towill, 2003, p. 137). This significant economic impact is the reason why SC management researchers particularly focus on the automotive industry.

Most of the OEMs that the first-tier suppliers produce for are the so-called 'Big 3' OEMs. The Big 3 OEMs are the most dominant automotive producers in the world. For example, the Big 3 in the United States (US) are General Motors, Ford and Chrysler, the Big 3 in Germany are Volkswagen (VW), BMW and Mercedes-Benz, while Japan's Big 3 include Honda, Nisan and Toyota (Aoki & Lennerfors, 2013, p. 74; Curkovic, Vickery, & Droge, 1999, p. 32; Pries, 1999, p. 77). Components include engine parts, driver assistance, and wheel bearings among thousands of other car parts. Typically, suppliers will offer over 5,000 products, with some cataloging up to 100,000 items, making supply networks very complex (Childerhouse et. al., 2003, p. 138). There are thousands of first-tier manufacturing firms that specialize in the automotive industry.

1.2. Objectives

The main purpose of this thesis is to investigate disruptions found within the supply chains of first-tier automotive suppliers and investigate risk mitigation strategies that have been developed by SC managers to counter these disruptions. Through these findings, the objective is to discover which risk mitigation strategies have been been implemented to protect against major disruptive events.

Before the research questions can be addressed, the following establishing question must be answered for clarification:

- **How are SCs of first-tier automotive manufacturing firms currently structured and have any issues arisen due to this structuring?**

The research questions are split into two, answering:

- **How were first-tier automotive suppliers affected by SC disruptions due to the COVID-19 pandemic?**

- **Which disruptive risk mitigation strategies have been implemented and how have they affected firms' operational capabilities?**

Through these two research questions we can then answer the follow-up question:

- **How is the future of SC in the first-tier automotive industry predicted to look in the years following the pandemic?**

1.3. Structure

An efficient way to address these questions is to conduct an exploratory holistic multiple-case study. The details of what this type of study entails can be found in §3. A sound and solid way to get up-to-date primary sources of information for a multiple-case study is to perform interviews with key members such as SC managers of first-tier automotive suppliers. Through these interviews the problem definition and research questions can be properly addressed.

As part of this research, a literature review (§2) was included to determine the risk types found within the SC, explain the growing complexity of SCs along with effects that disruptions cause, and finally disruptive risk mitigation strategies that have been enforced in the past.

Secondly, the methodology used in conducting interviews with key players is addressed, as well as the analytical steps used to obtain the information needed from the interviews for qualitative analysis.

Thirdly, the interviews are analyzed in detail to find how disruptions affect first-tier auto suppliers and which risk mitigation strategies have been used.

Fourthly, from the results of the analysis, the research questions are answered and the literature review and data results are compared to check for consistencies and discrepancies.

This thesis ends with a summary of phenomenon found in the research, contributions to practical and theory development and limitations of the case study.

2. Literature Review

The thesis is split into three main sections. 2.1. is a brief summary of the structure of the entire automotive industry from the OEMs up to the raw material suppliers. 2.2. clarifies the first research question on how disruptions affect supply chains and why, while 2.3. elaborates on the second research question by showing which risk mitigation strategies are commonly used to help fight such disruptions.

2.1. Structure of the Automotive Industry

The automotive industry is generally split into OEMs, first-tier, second-tier and third-tier suppliers. OEMs focus on the core competences of the automotive industry, including the design and final assembly of the entire vehicle. Examples include famous brands such as VW and Ford. First-tier suppliers deliver complete parts specifically meant for the OEMs, such as seats and tires. Second-tier suppliers provide smaller individual components and parts for both the OEMs and first-tier suppliers, such as lighting fixtures. Finally, third-tier suppliers usually provide single, mostly raw-material products, for second-tier suppliers, such as glass or steel (Messina et. al, 2015, p. 1).

The entire automotive industry takes on a resource-based view (RBV) when engaging in supply chain risk management (SCRM). RBV occurs when the rate, direction and performance implications are taken into consideration when a diversification strategy for resources is taken into account. These resources include equipment, land and tangible capital that are needed to be bought from other firms to produce products. Level of profits with resources can be greatly influenced by physical inputs brought into the firm (Mahoney & Pandian, 1992, p. 363-369).

These strategic resource decisions are of particular importance in the automotive industry, in all tier-levels, due to the high number of resources that are needed for only one product. Managers should ask themselves key questions pertaining to RBV, such as which resources should be diversified. This diversification of resources is particularly important when it comes to rare resources, such as certain metals, to increase the likelihood of buying inexpensive while receiving good returns (Wernfeld, 1984, p. 172).

2.2. Risks associated to the complexity of SCs and their theoretical effects

The second part of the literature review indicates the types of risks that are found among first-tier automotive firms due to the growing complexity and the theoretical effects that are found upstream and downstream the SC causing operational and financial losses.

2.2.1. Types of risks

Encarta Dictionary defines risk as the "…chance of something going wrong. The danger that injury, damage, or loss will occur" (Soukhanov, 1999, p. 1546). To implement an effective SC disruptive risk management, one first needs to understand what types of risk cause disruptions within the SC. Risk refers to events that are unlikely to occur but may happen suddenly and expectantly, having major adverse consequences along the SC. Risk is a part of uncertainty. Uncertainty is defined as an "…unpredictable thing. Something that nobody can predict or guarantee" (Soukhanov, 1999, p. 1933). In this case, uncertainty occurs when SC demand and supply are not matching due to external influences that cannot be predicted accurately beforehand and thus, unable to be effectively managed (Tang & Musa, 2010, p. 26; Manuj & Mentzer, 2008, p. 134). Although uncertainty cannot be properly assessed and reduced, risk can be reduced with properly implemented mitigation strategies. Hence, why managers focus on risk reduction.

SC risk can occur for various reasons. Risks can happen due to the actual physical movement of supplies, the flow of both money and information, or relationships between SC partners and suppliers. The biggest logistics risks can flow through and negatively affect goods, information or money (Dani, 2009, p. 55; Spekman & Davis, 2004, p. 417). Any discrepancies with the above mentioned indicators, whether they be physical, financial, informational or relational, can cause a disruption along the SC.

The reasons for SC risks can be broken down even further: quality, supplier capacity restraints, adjustments in the arrangements of suppliers, failure to lower costs, and unforeseen delays in transportation (Spekman & Davis, 2004, p. 419-420). Although they all have the ability to severely disable the SC, in this thesis we are focusing primarily on delay and supply disruptions, which are systematic events out of which managers control such fires, strikes and epidemics. A disruptive event is any sort of unexpected and unwelcome interruption or suspension of daily activity caused by an outside influence (Soukhanov, 1999,p. 520)

These SC risks cause disruptions that are influenced by specific types of risks. Supply risks occur with the initial supplier causing a disruption of inventory, scheduling, pricing etc. Operational risks are caused by the focal firm dealing mostly with inefficient manufacturing capabilities. Demand risks are started from the customer and can be caused by a chaotic change in the system. Other risks that can occur include resource, sales, competitive and security risks (Manuj & Mentzer, 2008, p. 138). The focal firm, found in the middle of Figure 1, in our case, represents first-tier automotive suppliers. The suppliers, to the left of the focal firm, indicate second and third-tier suppliers, while the customers, to the right, indicate OEMs and the ultimate consumers, in this case being the vehicle owners.

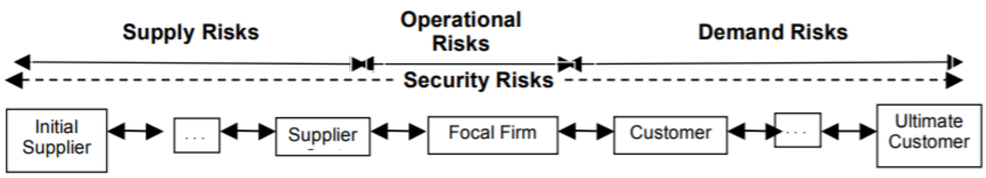

Figure 1: Risks along the entire SC
Source: Manuj & Mentzer, 2008, p. 138, Adapted from: Mentzer, 2001

These risks negatively affect the finances of the firm. Researchers have been trying to reduce failure through predictive abilities such as financial ratios since the mid-twentieth century (Beaver, 1966, p. 71-72). However, due to the constantly changing environment of the SC, the way these methods are conducted has changed dramatically in the past 60 years.

Risk reduction can be followed in four steps. First, the risk must be identified within the focal firm in the domestic environment. Answer questions such as: ‘is it a demand risk or supply risk that has caused the disruption?’. After correctly identifying the type of risk, the second step is to assess the risk and evaluate it by estimating the likelihood of the disruption materializing and the potential loss that can occur. Step three is to identify and then implement a risk mitigation strategy. Finally, in step four, the mitigation occurs and the manager must now analyze the implemented strategy (Dani, 2009, p. 56; Manuj & Mentzer, 2008, p. 144). The types of strategies will be discussed in §2.3.

Next, we will discuss the growing complexity of the SC in 2.2.2 to 2.2.4, and the pitfalls that have a negative effect on the SC in 2.2.5 to 2.2.6.

2.2.2. Cycle of Survivability

During long-term, generally stable, economic times, the operations of a SC are under a positive or volatile feedback cycle. When it is under a positive feedback system, there are little to no disruptions along the SC, so the main goal of the firm is to simply maximize profitability. During a volatile feedback cycle, disruptions occur on occasion with usually quick recovery times. Here, the main goal is to restore the operations and performance systems as quickly as possible (Ivanov, 2020, p. 7).

However, the global economy is currently undergoing a survivability feedback cycle. Whenever there is a long-term global crisis, the main goal is simply for the SC to survive. As long as the SC continues to exist and serve society the products it normally provides, then it should successfully continue operations when it is back at a positive or volatile feedback cycle (Ivanov, 2020, p. 6). In order for survival to be possible, there is significant need for developing a viable and resilient SC with a strong contingency plan to protect the SC against the risk of major disruptions. Although major firms tend to survive, the smaller ones are more prone to permanent closure. Up to “…60% of small businesses never reopen [after] a disaster” (Katsaliaki, Galetsi, & Kumar, 2021, p. 2). Most first-tier automotive suppliers would be considered large sized enterprises. Although the chances of permanent closure is much lower than that of small to medium sized enterprises, larger firms can still lose large amounts of revenue, resources and employees. Due to the pressures of the pandemic, for example, the Swarovski production facility in Wattens had to let go of 1,800 employees because crystal sales fell below 2 billion Euros (Vahrner & Strozzi, 2020).

2.2.3. Viable SCs

For a firm's SC to get through the cycle of survivability and remain successful without collapsing it must be a Viable Supply Chain (VSC). A SC is viable when it can survive and continue existing after a major disruption in the environment through the re-designing and re-planning of both the SC structure and economic performance, taking into account the long-term impacts of such changes. Firms need to be survival oriented on a long-term scale by balancing reaction and disruption in order to remain viable (Ivanov, 2018, p. 59). There are a number of managerial strategies in order to remain viable during a cycle of survivability that we will cover in §2.3 of this thesis.

The notion of remaining viable and surviving during unstable times is not a new concept. The viability theorem indicates the importance of having set boundaries within a dynamic system that are able to maintain viability through mathematical solutions (Aubin, 1991, p. 2-3). The Viable System Model, another attempt to conceptualize viability, emphasizes that the complexity of social systems, such as a business unit, can be overwhelming to the system's regulators. Most managers focus on short-term goals such as monthly profitability, rather than long-term viability of the firm and thus the entire business system can become overwhelmingly complex during times of low-frequency high-impact disruptions, putting the firm in risk to long-term problems such as annual revenue loss (Beer, 1984, p. 10). Hence, the importance of having risk control mechanisms set in place within the entire business unit, which lowers the chances of the above mentioned consequences.

Although these particular concepts of viability did not refer specifically to SCs, it is easily transferable to VSC since it is a dynamic and constantly changing system. This idea of dynamic viability had been used to better understand new trends in the SC systems, from the introduction of the internet in the SC to reverse logistics management (Graham & Hardaker, 2000, p. 287-288; Lee, McShane, & Kozlowski, 2002, p. 152).

Resilience, which is determined by the level of disruption of a single and and impactful event, aims to both withstand and recover from the specific disruption of the said event and go back to its original, or improved, position as quickly as possible (Spiegler, Naim, & Wikner, 2012, p. 6163). There are stark similarities and overlaps that viability and resilience share.

However, viability's focus is on open-system long-term solutions, while resilience focuses on closed-system short-term solutions (Ivanov & Dolgui, 2020b, p. 3-4). Therefore, it is important for SC managers to look at both short-term and long-term solutions.

The importance of viability, along with resilience, throughout the SC can easily be applied to the automotive SC to ensure first-tier automotive suppliers survivability by assessing SC performance through such things as annual income or production levels. Various resilience methods can be applied including inventory buffers and back up suppliers to ensure that these managerial performance goals are met (Ivanov, 2020, p. 11). If such goals are achieved, viability can be ensured and the firm should be able to bounce back to the positive or volatile feedback cycle with increased production and revenue.

2.2.4. Intertwined Supply Networks

The complexity of VSC increases with the idea of intertwined supply networks. Ivanov & Dolgui define an intertwined supply network (ISN) as "…an entirety of interconnected SCs which…secure...markets with goods and service. The ISNs are open systems with structural dynamics…[and] may exhibit multiple behaviours by changing the buyer-supplier roles in interconnected or even competing SCs" (2020b, p. 1). Due to the complexity of such networks, the managerial solutions to disruption risk mitigation need to be different for each firm, industry and country. For example, the risk mitigation strategy for a first-tier automotive firm in Germany will be vastly different from the strategy used for a mobile phone parts manufacturer in South Korea. This complexity is the reason why supply chain researchers have not been able to come up with a 'one size fits all' solution.

Traditional SC strategies up until the mid-twentieth century focused on linear solutions, from raw-material suppliers directly down to the customers, by looking at simple variables such as the workforce of a factory and their production rate (Holt, Modigliani, & Simon, 1955, p. 3). However, as technology and globalization develop so does the complexity of SCs, and researchers can no longer look at the SC as just a simple line downwards from point A to point B. Figure 2 shows how closely tied firms are to each other nowadays compared to traditional models of the mid-twentieth century.

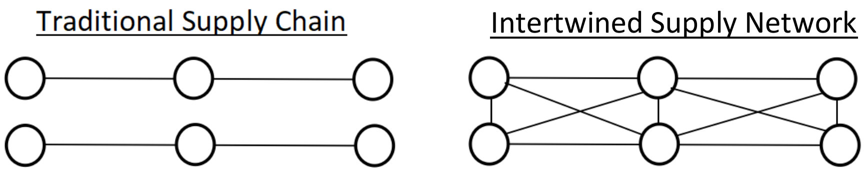

Figure 2: Traditional SC compared to ISN
Source adapted from: Ivanov & Dolgui, 2020b, p. 2

This change from a traditional SC to a modernized intertwined supply network, and the complexities that come with it, has made the current pandemic crisis extremely difficult to overcome. SCs today are usually open systems with dynamic networks. Single suppliers are, many times, supplying products to multiple other suppliers and OEMs (Ivanov & Dolgui, 2020b, p. 2).

The complexity of ISNs increases when you take into consideration that many competing firms serve as each other's suppliers, simultaneously creating a 'frenemy' relationship by agreeing to strategic alliances with one another to increase flexibility and performance (Liao, Lin, & Schih, 2010, p. 6868-6869). Many high-tech industries engage in such practices. Samsung, for example, has supplied Apple with processors for their iPhones for many years. Sharp, a competitor of Apple in the tablet and smartphone sectors, has provided Apple's iPads and iPhones with Liquid Crystal Display (LCD) screens (Niu, Li, Zhang, Cheng, & Tan 2018, p. 1). As cars become more and more high tech with such things as built-in touchscreen displays, such 'frenemy' partnerships are likely to be found in the automotive industry as well. If and how such frenemies exist and their consequences has not been fully researched.

2.2.5. Ripple Effect

The main reason why threats caused during the cycle of survivability exist is because of various disruptions caused within the ISN. Two major theories that can cause devastating effects along the SC are the ripple and bullwhip effects. The bullwhip effect, which we will cover briefly in §2.2.6, pertains to the upstream, recurrent dynamics operational risks based on inventory while the ripple effect corresponds to downstream, exceptional dynamics based on structure (Ivanov, Dolgui, & Sokolov, 2018, p. 2; Ivanov, & Schönberger, 2019, p. 464-465). Figure 3 shows that the bullwhip effect tends to happen more frequently than the ripple effect. However, the figure also shows that the ripple effect, although less frequent, has a bigger impact than the bullwhip effect on performance.

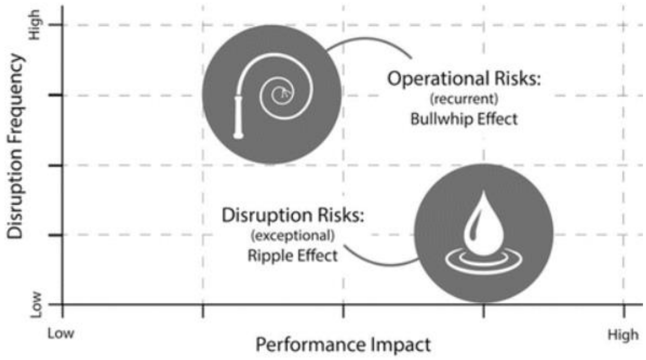

Figure 3: Contrasts between the ripple and bullwhip effects
Source: Ivanov, & Schönberger, 2019, p. 464

The ripple effect, caused mainly by supply risk, occurs when a low-frequency high-impact SC disruption is unable to be limited or enclosed to a single point within the SC, and rushes downstream causing a highly impactful effect on SC performance (Dolgui, Ivanov, & Sokolov, 2017, p. 415). The impact of such abrupt downstream disruptions can have devastating effects on firms all across the SC. These effects can include decreased revenue, loss of market share, lower reputation and delivery delays among other losses. Such effects can have long-term consequences; for example, empirical analysis has shown that "…stock returns relative to a three-year period" of time decreased by 33-40% (Ivanov, 2017b, p. 2-4).

Japan is a country known for its cutting-edge technology and efficient SC solutions. However, it is also a country that has had numerous disasters in the last couple decades that have greatly affected their SCs. These high-impact low-frequency events include tsunamis, earthquakes and nuclear meltdowns.

The East Asian nation supplies 60% of the globe's silicone used as a key component to semiconductor chips, which can be found in flash memory drives and

LCDs among other commonly-used products, that are produced by first-tier automotive suppliers. Following the disasters of the earthquake and tsunami of 2011, the global price of this material skyrocketed by 20% (Park, Hong, & Roh, 2013, p. 76). Any firm that bought silicone-based material from Japanese firms at the time were affected, even though it was an isolated area with no single supplier being at fault. This major disruption is an evident case of the ripple effect.

The global pandemic of 2020-2021 has resulted in an onslaught of the ripple effect across many industries all over the world. Due to the unanticipated and stringent lockdown in India from March to May 2020, online product availability of fruits and vegetables fell by 8%, edible oils dropped by 14% and cereal prices rose by 2%. Suppliers of fish, poultry and coffee also suffered while retail food prices rose during this time. Research found that one of the main reasons for these negative changes was inadequate warehousing and long SCs from rural to urban areas (Cariappa, Acharya, Adhav, & Ramasundaram 2020, p. 4; Mahajan & Tomar, 2020, p. 2-8). A number of automobile production facilities had to close in various firms and countries including Hyundai and Kia factories in the US, Brazil, India and Mexico (Hehr, 2020). Many more newspaper articles since the beginning of the pandemic wrote of plant closures of both OEM and first-tier automotive suppliers causing an onset of the ripple effect. There were no academic sources found on the actual number of plant closures and their effect on SC disruptions. It will be found in §4 how strong of a roll, if any, that the ripple effect had on the firms that were interviewed for this study.

The reasons that the ripple effect is so prevalent today are leanness and complexity. Firms now aim to be as lean as possible by having low-level inventory, single sourcing, and an inflexible capacity. Complexity, due to globalization and the increased intricacy of SCs with the introduction of ISNs, has made the connections of the SC tighter, longer and easier to snap (Ivanov, 2017b, p. 7). To break the reasons of leanness and complexity further down, there are four main sources that make the disruptive and exceptional risk of the ripple effect even more pronounced: 1. Sourcing strategies, such as single sourcing, 2. inventory management, like low-safety stocks, 3. production planning, such as 100% capacity utilization, and 4. control, particularly having no contingency plan, have all contributed to the impact of the ripple effect along SCs and within ISNs (Dolgui et. al, 2017, p. 421).

Although the costs of mitigating the risks of the ripple effect, through implementation of mitigation strategies and double sourcing, are indeed high, the risk of the ripple effect can have dire consequences on production levels and annual inventory. Hence, the importance of firms protecting themselves against such risks are vitally important.

2.2.6. Bullwhip Effect

Another effect that could have had a major influence on first-tier automotive suppliers, due to the current global pandemic, is the bullwhip effect. As briefly mentioned at the beginning of §2.2.5, the bullwhip effect, caused mainly by demand risk, is similar to the ripple effect with stark exceptions. These are not exceptional, disruptive risks that are witnessed in the ripple effect, but rather, operational and recurrent risks, primarily due to demand fluctuations. The effects are also usually upstream, meaning from the consumer up the producers. Here, the main effects are seen with inventory level fluctuation and their lead-times (Ivanov, 2017b, p. 5). The most prevalent symptoms that the bullwhip effect brings to the SC are inadequate product forecasts, disproportionate inventory, inefficient capacities, and poor customer service (Lee, McShane &, Kozlowski, 1997, p. 93).

A prime example of the bullwhip effect through the 2020-2021 pandemic has been the temporary but huge increase in consumer demand for toilet paper. This demand surged in many Western nations resulting in companies, such as supermarkets and toiletry producers, struggling to meet the influx of demand (Paul & Chowdhury, 2020, p. 284).

Such distortion of information for demand and supply of products affect many areas along the SC. Both the manufacturers' and retailers' warehouses end up over or under-stocking products (Lee et al., 1997, p. 94). It is important to note that both the ripple and bullwhip effects influence the SC of first-tier automotive suppliers' operational performances. How big of an impact both effects have had on first-tier suppliers will be determined in the data results.

2.3. Disruptive Risk Reduction Strategies

It is important for managers to prepare both proactive and reactive risk mitigation strategies to fully protect their firms against severe SC disruptions that have the potential to negatively affect their operational levels.

In proactive SC disruption strategies, probable risks are found and analyzed during the SC design phase. This assessment includes the possible disruptions and their likelihoods, impact and rank of importance. The main goal here is to develop a contingency plan to target and identify the disruption before they have a chance to impact the firm (Dani, 2009, p. 58).

Newer technologies, such as Radio Frequency Identification (RFID) Chips, the Internet of Things (IoT) and Artificial Intelligence (AI), have played a major role in increasing the efficiency, speed and accuracy of proactive strategies. AI refers to machine self-learning. IoT relates to the prevalent computing system in industrial practices, and the exponential growth of data and innovation through technological developments (Özdemir & Hekim, 2018, p. 3).

RFID chips are a newer technology that have emerged and replaced traditional barcodes for inexpensive automatic identification, tracking and tracing of products. They use a microchip and an antenna to pass information wirelessly (Asif & Mandviwalla, 2005, p. 394). RFID chips are found in almost all OEM and first-tier automotive suppliers today. Chevrolet, in the US, for example, uses RFID tags on their products in their warehouses. If there are any discrepancies found within shipments to or from the warehouses, a red light quickly identifies and fixes the problems. This upgrade has saved the firm many man hours and thus reduces labour and disruption costs (Angeles, 2005, p. 53).

Reactive SC disruption strategies, on the other hand, mitigate the risk after it has impacted the firm's SC. Once the disruption hits the firm along the SC, the organization needs to swiftly find which strategies it should implement to decrease the impact on finances and operations. However, reactive strategies can be very costly if not implemented strategically. It is therefore vital to find the optimal reactive strategies to minimize lost revenue (Shao & Dong, 2012, p. 202). Determining this optimal balance of risk versus reward has been something that researchers have struggled to find when looking into reactive strategies.

It is imperative to include both reactive and proactive capabilities on the chance that a disruption, such as a global pandemic, will occur (Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007, p. 146). §2.3.1 will discuss popular proactive strategies while §2.3.2 will talk about reactive strategies that are implemented, along with their shortcomings, by SC managers.

2.3.1. Proactive Risk Mitigation Strategies

Many firms create strategies that help protect them against high-frequency, low-impact risks along the SC. However, the same companies rarely develop plans to shield them against high-impact, low-frequency risks, such as the ripple effect (Chopra & Sodhi, 2004, p. 54). The follow section discusses proactive strategies, particularly forecasting models, that firms implement to counteract the causes of risks.

2.3.1.1 Digital SC Mapping Forecasting Models

Forecasting models are computerized simulation models that are set in place to help better predict upcoming major disruptions. They are used in contingency planning to soften the blow of the negative impacts of such unpredictable disruptions like the ripple effect caused by COVID-19, particularly, in industries with high-production costs like first-tier automotive suppliers (Nikolopoulos, Punia, Schäfers, Tsinopoulos, & Vasilakis, 2020, p. 1-2).

Research has shown a vast number of state-of-the-art forecasting models that have worked in the past and have shown to have positive outcomes during the current pandemic. Some key determinants in creating a good forecasting model include efficiency, lean practices and sustainability. When looking at these specific points, the goal here is to come up with a plan that reduces safety inventory and stock points in the SC, and using single sourcing with sustainable suppliers as often as you can (Ivanov, 2017a, p. 2).

In §2.3.2, we will be discussing the importance of multiple suppliers and back-up inventory. However, due the significantly increased cost of such activities, it is important to cut costs where possible, in a smart and efficient manner. The most effective method to balancing these two alternatives is by using forecasting and regression models.

Many forecasting models have been developed by decision scientists, applied mathematicians, and operational researchers through the usage of time-series and machine-learning methods. However, with the unpredictability of firms' and governments' reactions towards COVID-19, such as lockdowns and border closures, there has been a lot of confusion generated about which models work best. This confusion shows that there is not one particular forecasting model that can precisely predict the pandemic's developments (Nikolopoulos et. al, 2020, p. 3).

Digital SC mapping using deep learning methods through machine learning is one of the most popular and effective approaches towards forecast modeling (Nikolopoulos, et. al, 2020, p. 2). Other forecasting methods include regression methods, compartmental epidemiological models and agent-based methods (Nsoeisei, Mararthe, & Brownstein, 2013, p. 2-3).

Deep learning works by digitally mapping out the suppliers on all tier levels of a SC or integrated supply network by creating a SC map. Although one upstream supplier may seem insignificant to a firm downstream the SC, it has been found that the far upstream suppliers can disrupt the direct suppliers by up to 50%. Although data used by SC mapping is still limited, there is a vast amount of information about most suppliers that can be found along the SC via the internet, showing valuable information regarding buyer-supplier relations (Wichmann, Brintrup, Baker, Woodall, & McFarlane, 2020, p. 1). This strong linkage of all suppliers within the ISN magnifies the importance of supply network visibility. For efficient and capable SC risk identification and mitigation, it is therefore vital for SC managers to develop holistic mitigation methods that includes all suppliers through such methods as SC mapping through deep learning (Basole & Bellamy, 2014, p. 756).

SC mapping works by depicting which supplier of specific parts are located in certain global regions by mapping out the flow of each said region, showing who is participating within the ISN and how each firm is dependent on their suppliers by using deep learning computer algorithms. Such algorithms include Neural Networks and Artificial Neural Networks (Wichmann et al., 2020, p. 3-4). This family of machine learning, which loosely resembles the neural networks in the biological brain, uses artificial 'neural networks' to gain access to multiple other units and then computes the connections to find the 'activation value' along the SC. These networks consist of stacked layers, many of which are concealed within the input and output layers. The term deep learning comes into play at this stage by diving deep into the hidden layers to find connections and creating a 'depth' to the model (Goodfellow, Bengio, & Courville, p. 5-8, 2016).

If more firms implemented SC mapping through deep learning, it would greatly increase the ability to more accurately find, and mitigate, risks before they have a chance to reach said firm along the SC. The moment a slight disruption is detected, a firm can prepare itself by securing backup suppliers or increasing their inventory before the disruption has had a chance to negatively affect the firm's performance output (Wichmann et al., 2020, p. 2).

Other forecasting models include simulation optimization and metapopulation models. Many of these models were specifically conceived to forecast demand and supply during an epidemic (Nsoesie, et. al, 2013, p. 2). Since the beginning of the pandemic, software companies and researchers have been rapidly developing live simulation models by inputting governmental decisions, such as border closures, which have been put online through freely accessible websites (Nikolopoulos et al, 2020, p. 2).

Every major automobile manufacturer, including VW and BMW, have used forecasting models to better predict how the pandemic would affect their SCs, hence, the high rate of success in getting through this cycle of survivability and continuing to generate revenue. It will be found in §4 whether first-tier automotive suppliers have implemented any forecasting models as well.

2.3.1.2. Digital Twins

To elaborate even further on digital algorithmic solutions through computer forecasting models, is the usage of a digital twin. A digital SC twin is "…a computerized digital SC model that represents the network state for any given moment in real time, allowing for complete end-to-end SC visibility to improve resilience and test contingency plans" (Ivanov & Dolgui, 2020a, p. 2). The use of IoT, AI and other major technological progressions, have introduced the idea of Building Information Models (BIM) which are platforms that accurately record all building information for planning and maintenance throughout the life cycle of the facility (Khajavi, Motlagh, Jaribion, Werner, & Holmstrom, 2019, p. 147406). As illustrated in Figure 4, BIM and digital twins work in unison to reduce the costs of disruptions and mistakes as quickly as possible.

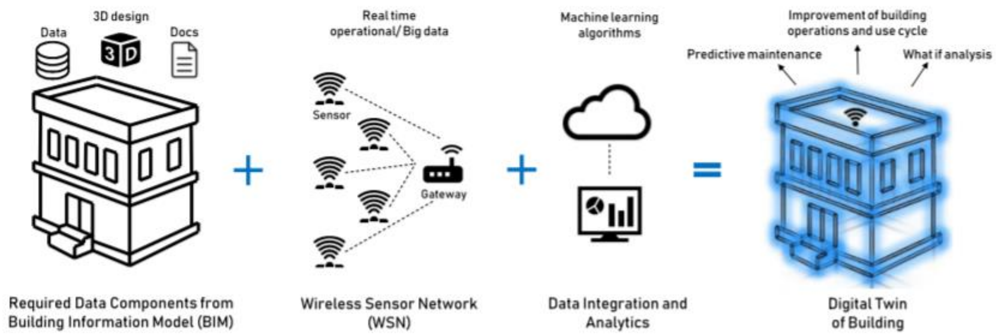

Figure 4: Integration of BIM into a digital twin
Source: Khajavi et. al., 2019, p. 147407

Although it is important to incorporate both digital twin and BIM into the firm's contingency plan, BIM focuses more on the building and warehousing capabilities while digital twins are more focused on transportation, inventory, supply and demand, and capacity data. These areas of focus on digital twins help SC managers plan for real-time control decisions by creating the best contingency plan possible (Ivanov & Dolgui, 2020a, p. 2). Figure 5 shows just some of the disruptive events that are then filtered into the simulation model using real-time data and predictive analysis to indicate the potential outcomes for the SC through the usage of various proactive and reactive strategies.

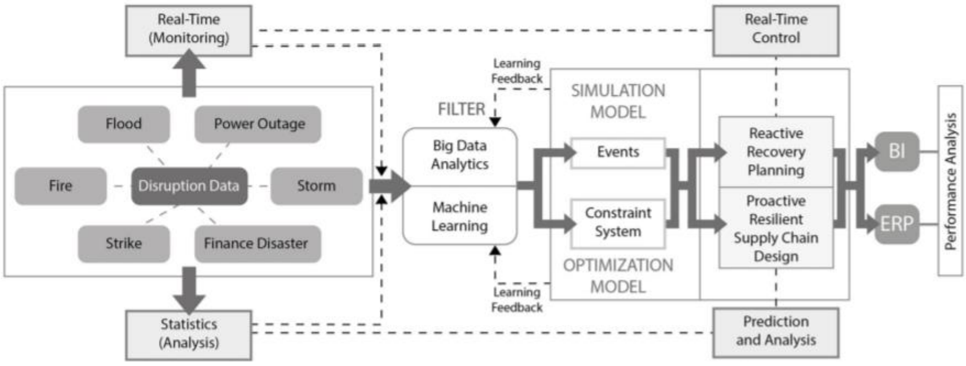

Figure 5: Use of digital twin for managing disruption risks
Source: Ivanov & Dolgui, 2020a, p. 7

Digital twins follow a general four step process. Step one, historical and geographical data is collected and computed into a simulation model. Step two, risk disruption analytics searches for any and all possible disruption data. Step three, simulation recovery policies are run from real-time data of inventory, lead times and capacities. Finally, in step 4, the output of the simulation shows the disruption impact and how the simulated recovery policy implemented affects performance levels (Ivanov & Dolgui, 2020a, p. 6-8). Through the usage of forecasting methods, such as digital twins, SC managers can better predict upcoming disruptions and thus, can be well-prepared with minimal increased costs.

2.3.2. Reactive Risk Mitigation Strategies

Forecasting models, such as a digital twin, are great proactive disruption management strategies, but it is also important to have reactive strategies as well (Thun & Hoenig, 2009, p. 247). Two forms of reactive strategies, multiple suppliers and safety stocks, are discussed below.

2.3.2.1. Multiple Suppliers

One reactive strategy is to have multiple sourcing. Firms implement multiple sourcing when they have back-up suppliers for certain products they commonly buy from (Sheffi, 2001, p. 2-3). Until the mid 1990's, it was usual for firms to have only a few key suppliers. However, with the Internet boom in the late 90's and the ripple effect caused by 9/11 along the SC, having multiple suppliers became more of an economical and rational strategy. Companies may now prefer to have both local and oversea suppliers, using cheaper foreign suppliers for the majority of their volume, while using more expensive local suppliers as back-up, in case a global disruption occurs (Sheffi, 2001, p. 2). If a supplier ends up unable to supply the products downstream, then at least a second supplier is able to deliver the parts.

With the increased costs of such redundancies, these financial 'losses' can be justified if interpreted as an insurance premium (Thun & Hoenig, 2009, p. 247). Every major firm needs to have some sort of insurance within their financial budgets to safeguard themselves against disruptions.

The idea of multiple sourcing is not a new one within the global OEM and first-tier automotive industry. BMW, Mercedes-Benz and Volkswagen (VW), Germany's 'Big 3', strongly suggest to their global suppliers to build their plants in various places around the world where they themselves have plants (Pries, 1999, p. 84). Other major automobile companies and their first-tier suppliers also have similar strategies.

VW had a plant in Puebla, Mexico. In the 1990's, when they were looking for local suppliers, the share of suppliers in the country rose from 20% to 50%. This explosion of local suppliers helped VW truly transform into a 'globally operating company'. In 1990, the Pueblo plant had a gross productivity growth of 6.75 cars per employee on average; in 1998, the average rose to approximately 23 cars per employee annually (Pries, 1999, p. 86-87). This surge was important as the new VW Beetle was being produced for the North American market. Production started in 1998, with only 320 models being produced. By 1999, 106,627 units were produced (Nuñez, 2006, p. 15). Although there was no ripple effect occurring, the bullwhip effect was clearly shown with a huge jump of demand for the new automobile that could not have been met without VW having multiple suppliers globally.

Due to the high costs of having a multi-supplier strategy, managers need to develop a portfolio, picking suppliers that produce for customers in different global regions. These first-tier suppliers should have differing strategies that do not have close relationships with one another that can end up conflicting with their customers (Wagner, Bode, & Koziol, 2008, p. 159).

With a well-developed multi-supplier portfolio using both local and oversea suppliers, the balance of increased costs with risk reduction can be met.

2.3.2.2. Safety Stocks versus Just-In-Time

Another common reactive strategy to combating disruptions within the ISN, that SC managers use, is to implement back-up inventory, otherwise known as safety stocks. Many managers do not want to invest in contingency methods that include back-up inventory as it greatly increases their costs (Zsidisin, Panelli, & Upton, 2000, p. 196) Although an increase in safety stocks could save a SC from the ripple effect, the question is if the back-up inventory is worth the high additional costs.

In the 1980's, Toyota, one of the largest automobile suppliers in Japan, sped up the production rate process significantly by introducing the just-in-time (JIT) production system by using new technologies such as multi-purpose machinery and single 'one touch set up'. JIT eliminated long time periods for loading and unloading products. This process quickly made its way into the Western European and North American automotive markets as well (Turnbull, 1988, p. 9; Hudson & Sadler, 1992, p. 41). JIT is still a common tactic used by OEMs and first-tier suppliers due to its great economic benefits; higher amounts of product can be assembled at a cheaper price through this method.

In one study, two automotive firms in Malaysia were analyzed to see how they protect themselves against disruption risks along their SCs. The most common technique for both firms was to create a month and a half of safety stocks (Hudin & Hamid, 2015, p. 801). This increase in safety stocks gave both firms the assurance of enough inventory, even if the SC has been temporarily disrupted.

The strategy of increased safety stocks works well for low-value commodities with low rates of obsolescence (Chopra & Sodhi, 2004, p. 58). Most of these commodities are not cheap and many high-tech products, such as GPS systems, may need to be replaced with more updated processors, making these said products obsolete within a yearly time frame. The costs of keeping such first-tier automotive parts can skyrocket if reserves are built up in an "undisciplined fashion" (Chopra &

Sodhi, 2004, p. 54). For JIT to work, firms along the SC need to keep a strong and consistent relationship with their suppliers. If the relationship is not cooperative and reliable, then firms downstream the SC will not be able to plan properly when a disruption occurs (Aksoy & Öztürk, 2011, p. 2747). It is therefore recommended that automotive firms use JIT assembly and have a strong contingency plan and forecasting model before increasing back-up inventory.

However, as seen in the Malaysian example above, having safety stocks is a tactic that some automotive firms still choose to employ. We will find out in §4 if this is a common tactic that first-tier automotive suppliers have used to fight the pandemic and maintain a VSC.

3. Methodology

This thesis is based on epidemiological behaviourism study, which focuses on arguments supported with sufficient evidence through cognitive behavioural problem solving of an issue (Garrison, 1995, p. 720). In this study, the importance of risk management strategies are supported with interviews through the comparative analysis of academic journals and interviews to solve the SC disruptions caused by COVID-19.

A holistic multiple-case study design was selected. Here, there is a single unit of analysis being conducted using multiple cases as data (Yin, 2018, p. 48); the data gathered here is through multiple interviews by managers. The data was analyzed through a conventional content analysis approach, which determines the presence of certain words, themes or concepts through the frequency of text gathered from primary data, such interviews. This approach finds and describes phenomenon and new insights when existing literature is limited (Hseih & Shannon, 2005, p. 1278-1279).

Furthermore, a case study finds the micro-macro links in social behaviour, whether that be in sociology, economics, management or any other behaviour-based study. It is conducted to get a deeper understanding of a topic with fleeting knowledge about the decisions made by individuals or groups about a certain topic (Gerring ,2007, p. 1).

There are three main purposes to a case study: 1. exploratory, 2. descriptive and 3. explanatory (Yin, 2018, p 8). The case study being conducted here is an exploratory case study since we are trying to explore what can be learnt from the managerial decisions made (Yin, 2018, p. 10).

A literature review (§2) was completed, before the interviews with key players, that identified complex social phenomenon and established the strengths and limitations of SC risk mitigation strategies (Yin, 2018, p.4-5). The literature review helped determine the themes for the interview process. These themes and their sources can be found in Appendix A.

The interviews were semi-structured, which allows for an informal environment and great flexibility in questioning. This interview style still implements structured pre-meditated questions but also allows interviewers the freedom to establish a rapport with interviewees through follow-up questions for further classification and details. Although the questions are structured, this adaptation of allowing for probing questions grants the interviewer the ability to get to know the interviewees' views on a more personal level (Turner, 2010, p. 755).

Semi-structured interviews are frequently used in case study research due to its mix of flexibility and structure. This method suggests that six to twelve well-chosen and well-phrased questions are asked, with two to four sub-questions prepared in cases where further clarification or details are needed (Rowley, 2012, p. 262-263). With the type of interview in the case study selected, it is important to follow a set of steps to get the most useful feedback possible.

The interview questions themselves should answer only how and why, avoiding yes or no answer questions (Yin, 2018, p. 118). The questions that were created for these interviews came from a mix of inductive and deductive research. Inductive research is done primarily by looking into theories that have been deeply researched. As long as the sources are cited, you can adapt questions from secondary research into your interview. Deductive research, on the other hand, uses data gathered to deduce an independent theory. The questions based on deductive research are mostly created based on practice and experience (Rowley, 2012, p. 263). This mix of research allows for both flexibility and standardization in the entire interview process.

The interview questions that were created for this case study were taken from a previous study done by Craighead et. al., covering a similar theme but on a broader sense, which included 8 questions (2007, p. 154). The questions by Craighead et. al. helped give a basic overview to the creation of the interview questions for this thesis, and thus 7 new questions were created. The interview questions, and their thematic coding, for this study are found in Appendix B.

The first step to the interview process is to set up the initial emails and LinkedIn messages to the managers of the first-tier suppliers. The preparation stage is vital to providing the maximum interview response rate. This success rate hangs on an explicit focus as to how the interviews will be written and conducted (Turner, 2010, p. 757).

To find potential respondents to message, LinkedIn recommends using the “People” tab in the website’s search tool. The “filter” option can also be used to find certain jobs in certain regions (Beaton, 2017) For example, for the first-tier automotive manufacturing firm Continental, tags such as ‘supply chain’ and ‘logistics’ were used to find employees in those field only.

To find the emails of potential interview participants, google searches such as ‘communications contacts’ were searched, along with the company name, to get direct access to the employees of the firms.

There are a few key things which need to be mentioned in the email or message within the initial request for an interview. Firstly, indicate who you are and which university you attend. Then, write a very brief overview of the research being conducted. Clearly indicate how long the interview will be and make sure to ask for permission to record the interview while assuring the potential respondent of confidentiality. Include details that would benefit the respondent and end the message with your contact details (Rowley, 2012, p. 264). The initial email and LinkedIn message used in this particular case study are included in Appendix C.1 and C.2.

The second step of the interview process is to conduct the interviews. It is best to start by practicing the process with a friend or colleague by conducting a pilot interview, which is a practice interview that is not included in the data results. The pilot phase allows you to refine the data collection in both the aspects of data content and procedural steps (Yin, 2018, p. 107).

In the pilot interview conducted for this study, a friend was first given a brief overview on the topics covered in this thesis, as well company information, such as product ranges and location. The 30-minute pilot interview was conducted on Zoom.

The seven official interviews were then conducted the following month. They were recorded and transcribed using the online transcription software otter.ai. Each respondent signed an ethics assessment consent form for their legal protection. The consent form can be found in Appendix D. Follow-up emails and LinkedIn messages were sent within 24 hours to thank the interviewees for their participation.

After all interviews were conducted, the information found needed to be organized and codified in order to retain the required data from the raw interviews.

The codification software for thematic qualitative data analysis (QDA) used was NVivo. The structure in NVivo allows for the interviews to be formatted. This feature can modify codes by adding key columns, merge tables from additional respondents, use a 'find' function for specific codes or wording and can be sorted in numerous ways from region of organization to question number (La Pelle, 2004, p. 86). With all these features readily available it was found to be more straightforward and accessible than traditional manual paper methods.

According to research conducted by La Pelle, the process for coding and retrieving qualitative data is done in six steps, as shown in Table 1. This process was generally adhered to for this thesis.

Step	Process step description
1	Format data into tables with respondent's identification and utterance sequence number included.
2	Create themed codes in tabular format for defining linkages between ideas.
3	Choose data categories for retrieval and include the data in columns for coding purposes.
4	Modify the columns in the table when coding text with multiple themes is required.
5	Sort the data of the categories of theme codes and data for pattern matching.
6	Validate coding and correct any mistakes for proper interpretation.

Table 1: Process of coding quantitative data
(2004, p. 87)

The quantitative data that was codified through NVivo, can be further organized based on levels of interpretation. There are four levels:

Level 1 gives formal definitions to the statistical measures (Kritzer, 1996, p. 5). An example here could be the question "how is your SC structured?" since most first-tier automotive SC's are structured in similar ways.

Level 2 helps to identify the problems that the qualitative data is trying to analyze (Kritzer, 1996, p. 7). The question "how has your firm's SC been impacted by COVID-19?" helps target the specific issue which needs to be answered in the case study.

Level 3 connects the "statistical results to broader theoretical patterns" (Kritzer, 1996, p. 9). By asking the question "which, if any, SC risk mitigation strategies did your firm employ?" and looking into the operational levels of the firm, compared with others in the study, the linkage can be made between theory and results.

Level 4 adds to the main three levels by finding what the most likely outcomes of the future will be.

After the codification process, the transcripts then needed to be interpreted and recorded in §4. Here we are looking to describe any phenomenon and include as many impactful statements as possible from the transcripts of the interviews. Respondents gave a structural and textual description of the phenomenon experienced using verbatim quotations, in this case the phenomenon being SC disruptions, particularly caused by COVID-19, and risk mitigation strategies used. A composite description was then written to conceptualize the findings and implications that the respondents gave (Akinade et. al., 2019, p. 4), which is found in §5.

Afterwards, figures and charts were created to give a visual aid to sum up some of the findings found within the results. Charts were created on MS Word, while figures were created on the app Lucidchart, which helps the user make professional looking figures quickly and accurately.

With the data properly codified and analyzed, the results of the information collected were clearly and consistently interpreted. This method helped answere the research question.

4. Data Results

To find the answers to our research questions in this case study, 7 33-to-65 minute semi-structured interviews were conducted, one of which was held with 2 participants thus having 8 respondents in total. All together there was a total of 4 hours and 45 minutes of recording.

The key players that were identified and interviewed included the executive of a crisis management team, logistics head, and various types of managers. All participants have been working, either for their firms or within the automotive field, for a minimum of three and a half years; the exact length of employment was not included as to ensure full confidentiality of the respondents.

Five of the firms that the respondents work for are first-tier automotive suppliers. Two of the firms are industry solutions specialists, with the respondents working specifically in the automotive sector. The perspective of both goods (suppliers) and services (consultants) was vital in gathering the most holistic data possible. Table 2 indicates all vital information regarding the respondents and their firms.

Interview	Respondent's Position	Country	Firm Services	Firm Type
Firm A (I1)	Head of Global Crisis Team	Germany	Breaks, fuel systems etc.	1st tier auto supplier
Firm B (I2)	Global Category Manager	Germany	Electronic units, roof systems, etc.	1st tier auto supplier
Firm C (I3)	Market Research Analyst	Italy	Forecasting and benchmarking	Industry Solution Services
Firm D (I4)	Head of Global SC Management	Germany	Mainly lighting	1st tier auto supplier
Firm E (I5)	Head of Logistics Europe	Austria	Almost all auto parts except tires	1st/2nd tier auto supplier
Firm F (I6)	Area Sales Manager	Switzerland	Tires	1st tier auto supplier
Firm G (I7.1) (I7.2)	1. Associate Manager 2. Associate Manager	Germany	Transformation of future mobility	Industry Solution Services

Table 2: Firm and Respondent List
Source: Own creation

All respondents that were interviewed have remained anonymous to the public due to the sensitivity of the confidential information revealed.

The interview quotations found in the results are structured in a simple and efficient manner. Interviews are cited using the letter I to represent Interview, followed by the interview number. All quotes are *italicized* to indicate speech. Within the quotations, the symbols **[ ]** and **…** can be found. Words found within the brackets [ ] indicate corrected grammar or a part of speech that was not completely understood in the recording. The symbol … indicates a skip in speech that is irrelevant for the quotation.

Each quotation and specific reference can be found in the transcripts, located in Appendix E of the digital copy of this thesis. Since Interview 7 had 2 respondents, Respondent 1 is indicated as 7.1, while Respondent 2 is indicated as 7.2. As an example, (I7.2:143-45) indicates that the reference is found in Interview 7 by Respondent 2 in lines 143 to 145.

The interviews were used to identify, and analyze, SC disruptions and risk mitigation strategies.

Level one found how complex the SC of the firms were. The main aim here was to find any issues within the ISN that have been around long before COVID occurred.

Level two went even deeper to find out how COVID-19 disrupted the SC; what occurred within the firms in the beginning of 2020 and the initial reactions towards the disruptions caused by the pandemic. Theoretical effects, such as the bullwhip effect, were analyzed to see how they affected the firms' operational capabilities.

Level three was the most crucial to the research, finding which risk mitigation strategies have been implemented to counteract such disruptive events. The data revealed how effective both proactive and reactive strategies were towards mitigating disruptive risks caused by COVID-19 and other recent events. The question of whether firms should have safety stocks or stick to a JIT method was also revealed.

Level four followed-up on the two research questions by summing up where the future of the automotive industry, specifically first-tier suppliers, is headed.

4.1. SC Design Complexity

First-tier automotive suppliers provide thousands of components through bulk ordering. Examples include plastic parts to OEMs and tires to bus companies (I1:47-48, I6:14-19). Many first-tier firms sell electronic components such as sensor radars and all-wheel drive systems to OEMs (I2:25, I4:25). A first-tier can also be a second-tier supplier (I5:66). For Firm E, *we are tier-one, but…if we deliver some to Hanon, for example, they produce gears, so in that [case] we are tier-two* (I5:68-69).

Consultants work with the automotive industry to increase strategic sourcing of firms' SC (I3:38-39). They conduct SC vehicle component forecasting (I3:20-25) and analyze future mobility and digital transformations within the automotive industry through data collection (I7.1:26-28, I7.2:67).

Complexity in SC is very high due to worldwide suppliers. Respondent 1 of Firm G found that *many companies have the most complex SCs [he's] ever seen* (I7.1:158-159). Complexity is greatly reduced when dealing with only regional suppliers (I6:84-

86). *Regarding our suppliers, we have our own factories. So our tires…are produced in Europe* (I6:42).

To add to the complexity *the whole supply landscape is always a network* (I1:175) and lead times are very long in automotive SCs. It can take from 12 to 52 weeks to receive a supply (I1:308, I2:220, I5:247-249).

There is a high level of competition that increases complexity, which also creates frenemies. Firm D states that *we are serving our OEMs, and sometimes they will nominate even two competitors to serve that one product. So, for example, we serve to another tier-one supplier, and [yet] another tier-one supplier will serve to the customer* (I4:46-48).

Strategy for supplier location is chosen based on what the component is. Normally, a plant is close to the OEM. If it is a heavy component, such as seats, the supplier will be close-by. However, lighter labour intensive parts could be supplied from countries far from the OEM, such as Germany receiving supplies from China (I2: 383-385, I3:81-94).

The biggest issue that has been hampering viability for years is transparency. Low transparency leads to problems such as not knowing where all supplies come from (I5:361). Transparency gets worse the further up the SC, from OEMs up to raw material suppliers, as indicated in Figure 6 (I3:58-61, I7.2:140-143) However, from a sales perspective, this is not an issue for purely regional suppliers because everything is done internally between departments (I6:209-210).

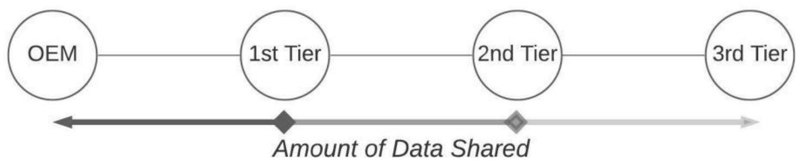

Figure 6: Transparency Decrease
Source: Own creation

The reason why there is not much transparency within the SC is two-fold.

It's always a legal topic, even with our direct-tier suppliers. It's not very easy to have this data because…[of] the unwillingness to provide the data, we *have to force them, but it's a long, long process* (I4:116-118) to obtain this data without contacting them (I4:107-108).

The sub-suppliers' unwillingness to provide data is due to competitiveness.

> *If you have the full transparency, given to the customer, you will lose maybe a certain negotiating position…this is always the same in the automotive industry because you have a lot of competitors and the cost pressures [are] very high* (I4:126-128).

Transparency can be increased by the Redwall process. This process requires transparency to be maintained along the entire SC (I1:178-179) by asking questions such as *in which situation is your supplier, in which situation are we, and in which situation are the customers* (I1:181). Data gathered through digital tools also helps increase transparency (I3:285-286, I4:86-88).

4.2. Disruptions

The first cases of COVID-19 were reported in China at the beginning of 2020 and quickly spread globally; *at the beginning, no one really knew what to do* (I3:212-213). Major SC issues started occurring immediately.

> *The biggest problem, when the pandemic started, and the preoccupation that people [had], was that products weren't going to be able to make it to Europe in order to start producing. So, [it] was a big surprise that…[it] had the complete opposite effect…the demand started increasing…[freight forwarders] really looked at a big increase [in] business, and therefore you had a lot of delays…in SC.* (I7.2:83-90)

COVID had an impact but not as big as people think (I5:88-92). The long-lasting effects were due more to side disruptions, such wood or steel shortages, rather than COVID itself (I5:150-155).

As soon as it was discovered in China, Europe started *taking measures to mitigate risk* (I2:143) by readjusting forecasts (I3:211, I6:456-457) and creating crisis teams (I1:70, I4:148). Some firms even started to producing face masks and alcohol for disinfectant (I3:214-216)

One of the biggest challenges from a sales perspective was *to bargain…that your customers have the willingness to accept and to get the stuff reserved* (I6:108).

The first effects were initial lockdowns of plants (I2:146) and carrier capacities carrying empty trucks (I1:222). Border and seaport closures also affected supplies (I1:214-215, I4:256) and thus initial production decrease (I2:148), these were clear indications of the ripple effect. R&D and technology innovation were one of the first costs to be cut (I3:133, I7.1:211-212).

North America and Asia also followed the same recovery process as Europe since they were affected the same way (I5:102-104). In North America, everything started and ended about 3 months later. North American workers found it more difficult to deal with home office due to cultural differences. The American president at the time also made the situation more complex by downplaying the virus (I5:453-465).

By <u>summer of 2020</u>, the COVID-situation started improving and plants started to reopen (I2:148-152, I3:217-218). However, component suppliers had a sudden ramp-up. Suppliers could not deal with demand and some OEMs re-closed (I3:219-220) thus creating a bullwhip effect. Electronic components had higher demand in all industries since lockdowns caused many to stay home and buy home electronic products such as computers and televisions (I2:153-156).

These disruptions caused lead-times of some suppliers to increase (I6:123). *In the current situation, we have components with a very long lead time. Some of them have a lead time of 52 weeks* (I2:328-329).

Many second-tiers were unable to live through this cycle of survivability, and the ones that did survive, learnt their lesson and started to diversify more products (I3:187-192).

By the <u>beginning of 2021</u>, side disruptions decreased operational capabilities again. The bottleneck effect occurred, increasing operational risks.

The electronic components were in a kind of bottleneck globally because, due to the COVID situation…[these parts] had a higher demand globally. For example, due to the lockdown, many people stayed at home. Many people started buying a computer…game console…new TV. And this had of course, also an impact on the global availability of components. (I2:153-157)

Some supply shortages were due to border closures. Even after borders reopened, transportation needed more time than normal to clear customs (I2:231-233). *It's a lasting effect at the moment, space on freights…space is really low…[and] sea containers are really expensive. The market is getting really expensive because of less space* (I5:171-173). In March 2021, supplies faced even further delays after a ship was stuck in the Suez Canal for almost a week (I4:240-241, I5:303).

It was difficult to get some components out of many countries, since different harbors and seaports closed due to regional lockdowns at different times (I4:256). Costs are very high for containers, a container used to cost $4000 but the price has now risen up to $12-13,000 (I4:243, I6:249).

The semiconductor shortage of 2021 caused a heavy SC disruption. It started around December 2020 (I4:171-172). The shortage could be because it has one of the longest pre-ordering times, about 26-weeks (I1:31-39). The ripple effect was found again since *VW, BMW have shut down production regarding the chip shortage* (I4:167-168).

The chip shortage strongly interrupted the SC of first-tier auto suppliers (I1:13-14, I3:116). However, the chip shortage was not due to COVID but due to a transition into the electronics market, although the pandemic did make the effects stronger (I2:274-275, I3:143). *It would come up in the next few years, it came now earlier* (I5:136).

The shortage particularly hit the automotive market hard since the entertainment and communications industries have higher priority over the automotive industry due to automotives being a small player in semiconductors (I1:260-261, I4:189-190).

There were some natural disasters that caused disruptions on the SC of plastic and electronic components. One of the events was an earthquake in Japan in February 2021 (I2:245-247). The ripple effect was caused since *production needed to stop, to check the product equipment, to check the building. So, there was the production stop in Japan [for] many suppliers* (I2:248-249).

Another disruptive event to halt production was a snowstorm in Texas, in February 2021. The snowstorm caused a major power outage with some equipment freezing and needing to be repaired. Both electronic and plastic production are now facing shortages (I2:251-255, I4:228-230). *Natural disasters [are] a big topic, but it's not the only topic, because…there are so many types of risks…political…trade…transport topics* (I4:230-232).

<u>As of mid-2021</u>, some firms feel that there is still a long road to recovery and the SC situation has not improved (I2:161-162, I4:171-173), therefore *we're still in global crisis mode* (I4:159-160). Some feel that the SC is close to being recovered and the situation has improved considerably (I1:122-123, I3:221-223). Others feel that their firms have already recovered since the situation barely hit them (I6:84-86).

Therefore, recovery is unsystematic, based on individual firms since there is no consensus on how quickly and strongly the first-tier automotive industry was able to recover due to *some better and some worse strategies* (I3:212).

> *I don't think anyone, about a year ago, expected…[it to] still [be] going on, that we're still in the situation and even though things are kind of back to normal because of different COVID measures that we have in place with the masks, the testing, the vaccinations. We're still not at pre-pandemic times, and it will take a while for us to actually get there. But I reckon we'll get back to where we were pretty quickly.* (I7.2:319-322)

Both the bullwhip effect and the ripple effect, and to a lesser extent, the bottleneck effect, occurred within the automotive SC due to COVID-19. It seems that at this point, that the ripple effect causes the bullwhip effect, with the bullwhip effect reoccurring often due to occasional mini-ripple effects. After the table below, which describes the timeline of the pandemic and the effects felt, both the ripple and bullwhip effect are further analyzed.

Event		Cause	Effect	Risk
1	COVID-19 pandemic	Disruptive event		
2	Plant closures	Supply decrease	Ripple	Supply
3	Electronics orders up	Demand increase	Bullwhip	Demand
4	Plants reopen	Supply increase		
5	Seaports/borders clog	Order delays	Bottleneck	Operational
6	Materials unavailable	2^{nd}/ 3^{rd}-tier shortage	Combined	Supply/ Demand
7	Semiconductors run out	1^{st}-tier/OEMs shortage		

Table 3: Timeline
Source: Own creation

Many suppliers and OEMs had to shut down their plants, halting production for up to 3 months (I2:215-216) causing the ripple effect and thus, increasing supply risks.

First-tier suppliers had to close down their plants and

> *reopen them based on the pandemic development in the respective country. So we started in China. Then, from China, the protection concept rolled over to Europe and later on to [the] US and Mexico following the pandemic, and Africa.* (I1:79-81)

Since the OEMs closed down, there was a sudden stop of production and output of supplies for first-tier suppliers as well (I3:130-131). However, although some first-tier plants closed (I6:142), the ripple effect was not felt by everyone and production went on as usual once the plants reopened (I6:180).

As previously mentioned, many firms greatly increased their orders causing the bullwhip effect, thus increasing demand risks.

It was found that change in consumption had *nothing to do with the shortages of any of the products…[but] from my point of view, the COVID waves* (I5:163-164) because *if an area is coming up after one wave, we increase the consumption, and on* *the other side…[during a wave we] cannot produce, so we have less products on the market* (I5:160-162).

Many firms increased inventory because if there are less components in the market, the immediate reaction is to order more causing an artificial increase in demand (I2:182-185). This huge rise in orders caused massive order delays causing the bottleneck effect and increased operational risks (I2:153-154). Forecasting became very difficult due to the volatility in supply and demand (I4:208-209). In the end, the SC's *were struggling to keep up with that demand that no one was expecting* (I7.1:110-111).

Even firms which do not require the supply of high-tech complex components, such as retread tires, felt the bullwhip effect. *It was a decrease…it was not that easy to manage…it's not everywhere that the customer is willing to pay more for a product that gives you the same benefits* (I6:163-165).

The ripple effect actually led to a major bullwhip effect as is described by Respondent 2.

> *Many companies needed to close because of the lockdown…[and] reduced their capacities because they needed to avoid building overstocks…and when the market started ramping up again, most of the electronic components have very long lead times…sometimes up to 6 months…and this is why at the beginning there was a shortage of components, because the ramp up could not be done according to the demands…there was a global increase of demand for electronic components right after the COVID crisis.* (I2:214-225)

In the end it was found that

> *You have both [ripple and bottleneck] effects and, of course, the challenge is to master them both…in a strategy which is not consuming too much cash because both effects are, especially also in the Corona pandemic…very valid. Some OEMs significantly increased their orders, because they feared that they were closing down, and then, of course, this is a self-fulfilling prophecy because then you're having way too many orders.* (I1:328-332)

4.3.1. Proactive Strategies

Forecasting indicates how much should be produced for customers, how much material is in-house, and how much will be used until a certain point. The system then indicates how much to order and if a little safety stock is needed (I5:380-383).

To create a powerful forecast one must first ask themselves, *what do we want to do, what do we want to achieve and what data do we need for this?* (I7.2:499). Mathematical models are then formulated using millions to billions bits of historical data (I4:333-336). Data intelligence integrated into SC forecasting models is very important in order for firms to manage risks (I2:320-321, I3:268) since *data is kind of the gold of the century* (I7.2:497-498). *It's not only about reducing costs and just trying to keep the cash flow within the company, but it's also about securing all the data which is the biggest asset that companies are generating* (I7.1:545-547).

Lengths of time may differ for firms. Firm B implements a two-year forecast, in which demand is updated weekly or monthly. Scheduling agreements are integrated into the model between OEMs and suppliers, allowing for the risk of only one month of production, any additional stock that the supplier has is at their own risk. Currently, with the shortages going around, 6 months are added for material relief for Firm B (I2:321-333).

Other forecasts, such as sales forecasts, can be implemented into the SC forecast for further data collection. Cost forecasting is done by sales managers by checking the quality of the supplies that are bought by customers. Tire manufacturers use special devices to see how much tread, which is the rubber on the tire that actually touches the ground, is left (I6:489-491).

Cost forecasting is usually done once to twice a year, depending on the type of tire and customer (I6:479-480). To get the most accurate forecast during the pandemic, the area sales manager of Firm F stated

> *I went to my 10 biggest customers, I [told] them that it will be tough with the availability this year and I [made] sure to get the accurate forecast of the need for the year during the spring, and usually I'm doing this job during the summer or during the fall* (I6:455-457).

The ultimate goal of forecasting models is to create a transparent SC (I3:268-269, I7.1:563). Although extremely difficult, due to unpredictable changes in demand, it is a realistic long-term goal to achieve transparency along the automotive SC since design cycles are not very fast with one product being kept in production for five to seven years (I2:341-344).

The biggest obstacle to achieving fully functional forecasting models are black swan events. These events are unexpected, very high-impact, low-frequency disruptions which cannot be predicted such as the financial crash of 2008 (I3:256, I7.2:501-502) and can produce unexpected supply and demand risks.

COVID-19 was a black swan event which weakened the whole SC (I6:269-270). These types of events are a huge issue since firms will never have control over them (I5:390-392). It is a big challenge to reserve capacities in advance through forecasting since no one can predict the future (I4:318-320).

If a major interruption can be dealt with before it happens, such as Brexit, then forecasting is not an issue. *Brexit is good because we can prepare, it's plannable…but the semiconductors or COVID, we cannot plan* (I5:414-415).

It is extremely important to have a digital twin integrated within the forecasting model in order to have clear transparency of the whole SC (I1:353-354). Digital twins work by uploading data onto a platform to map out various risk scores to find areas that are high and low risk (I4:360-362). Digital twins are combined with physical sensors. Firm A integrates a digital twin by applying s*ensors for automotive, that means electronics in the car, in the OEM and therefore, lifecycle management of our products…for the SC [which is]…supporting the digital twin* (I1:389-390). It was stressed by Respondent 1 that *you have to have a digital twin* (I1:368) for an efficient forecasting model.

For forecasting models and their digital twin to work efficiently, the latest technological advances need to be used. One such advancement are machine learning models, where different data is put together using AI to have an estimation of the upcoming risks in order to conduct real-time scans throughout the market (I4:374-376).

The leading firms of first-tier automotive suppliers implement IoT AI into their forecasting models (I1:380-381). AI should also be able to help predict, to a certain percentage, what can happen in the future and how specific actions can help improve the situation (I7.2:476-477).

RFID chips are not commonly used in the automotive industry to track supplies (I2:371-372). *RFID technology does exist, but it's not something we are using [as a tool] for the moment* (I6:510). The biggest problem with tracking shipments is that supplies cannot be tracked deep inside ships or trucks. However, the trucks and ships themselves are able to be tracked (I5:431-434).

Figure 7 indicates the most viable proactive strategy that SC managers can have within first-tier automotive manufacturing firms.

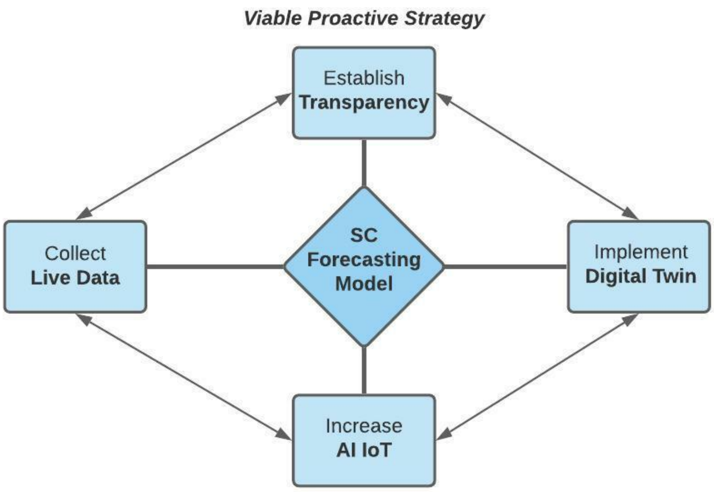

Figure 7: Proactive Risk Mitigation Strategies
Source: Own creation

It is important to note that

> *Data management and data integration…is becoming more relevant in order to be able to forecast better [and still] be able to operate in the same way,*

despite what happens in the world…a lot of companies have underestimated that, and many have already [made] many efforts to invest money on that part…it's becoming so much more relevant (I7.1:532-535).

4.3.2. Reactive Strategies

In regard to multiple supplier strategy, it is important always to look for a plan B and think about secondary sources to avoid a lack of supplies if a supplier has to halt production. There is always a supply risk attached to single sourcing (I1:183-185, I7.1:633).

To choose the most viable multi-source strategy possible, it is imperative to ask questions such as which suppliers could potentially jump in (I1:187-188), *what kind of part is being influenced by the lack of this raw material and if there's a quick…alternative solution…to change to a different product* (I7.2:641-642).

Another consideration to a viable multiple supplier strategy is regional differences. An *OEM might have a different supplier in Europe for a component, and also [a] different one in the US, and another one in China…they are different suppliers for different OEM locations* (I3:316-318).

For some firms, the strategic decision is to not source a product from another manufacturer. This decision only works if the component does not require many various complex parts, such as tires (I6:437-439).

With some components, having multiple suppliers is not even a realistic possibility. Semiconductors are a prime example. It is very difficult for the automotive industry to obtain semiconductors since the entertainment industry receives most of them (I1:259-261). If there are no suitable other options, *then you need to stick with the supplier, and you need to do all your escalation process with this one supplier, because there is basically no real alternative* (I2:390-392).

It is also important to look at where your rare supplies are coming from. Firm E had four companies that were selling semiconductors to them. It was later found that all four suppliers were in the same city with the same sub-supplier. Although Firm E had four different accounts with four distinct suppliers, the sub-supplier was, at the end of the day, the same firm (I5:329-335). This type of situation is the reason why asking questions upfront is so vital to a successful multi-supplier strategy.

Redesigning the product or introducing an alternative is not a viable option when multiple suppliers are not available for back-up. This process takes up a lot of time, which nobody has much of, and is not feasible because getting the supply in quickly is extremely important (I2:392-394, I5:354-355). Time is money; *inventory is always a big topic because you're talking about three digit million values…[and] of course…cash is always limited* (I1:274-275).

The whole automotive SC is lean under normal circumstances. The entire industry is on JIT, holding as little stock as possible (I1:301, I2:322-323, I4:451-452). *It's always more cost effective to not have inventory. And I think most of the companies still work based on that approach or method* (I7.1:588-589).

JIT needs to be incorporated with data and technology for full efficiency. Scheduling agreements should be implemented, where the purchasing order (PO) is already in the system several months in advance. Suppliers are able to see the inventory they need for up to 18 months, depending on the customer and supplier. However, this PO method is not even possible due to the current situation of global shortages (I2:410-416).

Briefly mentioned was also vendor-managed inventory (VMI). For Firm A this means that you have *inventory which is in the possession of the vendor…that is managed by IoT principles, [which] means if…inventory is running short, this is automatically ordered at the supplier* (I1:302-305).

The trend seems to be moving away from a purely JIT system. Having some safety stock ensures that you reduce your supply risks by decreasing your dependency on JIT (I7.1:591-592). *COVID showed us that for some components, it's a good idea to have some less capital intensive inventory* (I3:329-330). However, *normally, [the] supplier is close to the OEM side so that they have the perfect SC…for JIT* (I3:331-332).

Even though it increases costs, having safety stock is an investment to buffer any disturbances within the SC. Buffer stocks should be established for certain components (I4:453-456). This buffer stock is especially useful for small and inexpensive parts, such as screws, since it does not matter if you have 10,000 or 15,000 in-house (I5:311-312).

> *Companies have to weigh up the cost of having inventory compared to the cost of what the past year has brought with it. So, if the security of bringing inventory back to the factories is worth the extra financial cost.* (I7.2:601-602)

JIT is not popular from a sales perspective (I6:588). The salesperson is unable to deliver the product if inventory runs out. *My performance is evaluated on the basis of my turnover, and if I'm not able to sell the product, it will negatively impact my performance* (I6:589-590). Having enough safety stock reduces such sales risks.

Another reactive strategy that has been implemented to combat disruptive SC risks, such as COVID, are crisis task forces (I4:408-410).

Firm A set up their global crisis team at the beginning of 2020, when COVID was still in its infancy. One task force was specifically set up for SC. This task force was divided into approximately 10 sub-divisions, dealing with tasks such as logistics, production and purchasing. The manufacturing sub-division, for example, was responsible for the ramp-ups and ramp-downs when plants had to close and reopen based on the pandemic's development in different countries. These subdivisions helped reduce the bottleneck effect by indicating if there was a rise in operational risks (I:70-77).

Scenario planning plays a critical role in crisis management. This planning describes the status of the pandemic, from low incidence, to lockdown and then back to new normal. Through these scenarios, protection measures are created. The scenarios are then resharpened based on new findings. These constantly updated global scenarios ensure that everyone knows what to do (I1:96-102).

These teams proved to be very efficient throughout the pandemic. *I think [we did] that very well, so we did not have any major disruptions* (I1:242). Crisis teams will definitely remain, although after the COVID-19 crisis they will not be a part of day-to-day business. It is something that firms should prepare their employees for, in order to better react to disruptive events (I7.2:661-665).

The figure below shows the three most effective reactive strategies that should be implemented by SC risk managers, when possible, within their risk reduction strategy.

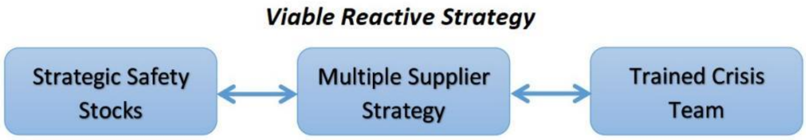

Figure 8: Reactive Risk Mitigation Strategies
Source: Own Creation

4.4. Future Predictions

The last 10 years have been the biggest transformation the mobility market has ever seen (I7.2:336-338). The *SC process for those companies was already changing…surviving the current situation has shaped a lot of customer preferences* (I7.1:385-386).

There is a transition towards a higher demand for electronic components which will greatly affect the global market. One reason being the hype for electric cars (I2:282-286). A lot of data-driven methods are being introduced to reduce risks. In the automotive industry, the speed is very slow for change. But, due to the pandemic and chip shortage, the ISN is transforming, and so, there is a growing push for digital innovations through R&D investments (I4:474-479, I7.1:685-687). Many firms are not yet digital; having a digital twin available is essential for clear transparency since there are still logistical areas that do not have full transparency of all the inventory (I1:352-355, I7.2:130-133).

One of the reasons China's economy continues to grow quite fast is because everything is produced in-house. Both Europe and North America need to rethink building up more regional capacities within their own regions so that they are not as dependent on other areas (I2:438-441, I7.2:127-130). Regional sourcing should be looked at positively when discussing purchasing. It should not always be the price which is important but the cost of ownership as well (I5:486-488).

A lot of OEMs, and also their suppliers, [are] rethinking their supply and SCs. And they might even double think if they want to open a new plant in [a] low-cost country. If this is worth the good investment, or pay even high salaries [regionally] and you have less stress on the SC. (I3:353-355)

There are a lot of start-ups happening in electronic components for autonomous cars (I3:388-392). A lot of new companies which are focused on electric vehicles, such as Tesla or Rivian, might surpass the classic automotive companies, thus drastically changing the market. This interruption on the market is one of the reasons why older firms need to focus more innovation (I7.2:330-338).

The future of hygienic measures in vehicle sharing is highly discussed. Pre-pandemic, there was a lot of focus on car sharing, such as Uber Pool. We need to rethink if we really are going to share as much as we predicted. There is now a stronger push towards such things as self-driving taxis since this would decrease physical contact between individuals. There are discussions on how to make shared vehicles more hygienic through material usage, such as the use of UV lights to detect germs (I3:359-365, I7.2:697-706).

JIT needs to be rethought as a risk management model. Although it saves some costs, it does not compare with the competitive advantage of meeting your customers needs on the spot. Having safety stocks on hand help firms react quicker to disruptions (I6:560-564).

5. Discussion

Through the combination of the four levels previously discussed, a cross-case synthesis was conducted, which is used specifically for multiple-case studies. According to Yin, this method helps "…identify key variables and then aggregate the cross-case data for each variable" (2018, p. 196). Using a cross-case synthesis, we were able to compare the disruptions and strategies, along with the SC structure, to find which strategies are most implemented.

The answers to both the establishing question, research questions, and follow-up question are answered here when comparing the firms.

Questions one to three are further analyzed by comparing the literature review (§2) and data results (§4) to find if there were any discrepancies between §2 and §4, as well as any missed data that the literature review did not find.

Level 1: Establishing question

- **How are SCs of first-tier automotive manufacturing firms currently structured and have any issues arisen due to this structuring?**

First-tier automotive suppliers, which sometimes also work as second-tier suppliers, produce components for OEMs. Many first-tier suppliers who compete against each other also sell to each other, making the automotive SC more of an ISN, and thus increasing complexity.

There is currently a demand for more electronic integration. This change into an electronic market is revolutionizing the automotive industry, forcing more established firms to take digitalization more seriously.

The most complex issue for first-tier suppliers is a lack of transparency within the SC due to the unwillingness of firms to share data with one another. This data shortage makes the creation of a truly VSC difficult to achieve.

Transparency was a major topic found in the data results but not in the literature review. However, this is a problem that specifically plagues the automotive industry; it is unknown from the research conducted if it is something that affects other industries as well. Other industries may potentially use other wording to describe this phenomenon, thus the term not being specifically mentioned within literature.

Level 2: First Research Question

- **How were first-tier automotive suppliers affected by SC disruptions due to the COVID-19 pandemic?**

During the initial global lockdowns because of the COVID-19 pandemic in the first quarter of 2020, there were constant plant closures globally. These closures caused a sudden drop in supplies since plants could no longer produce components, greatly increasing supply risk, and thus the ripple effect occurred.

By mid-2020, most plants reopened, although there were occasional regional lockdowns due to fluctuating COVID waves. By this time, consumer demand in electronics had greatly increased causing an increase in demand risk, and so the bullwhip effect transpired. Due to the increased demand, suppliers released a very high number of products all at once, which overwhelmed borders and seaports, causing operational risks such as delayed orders. These mass orders stuck in-transit was a sign of the bottleneck effect.

By the beginning of 2021, supplies would run out due to sudden regional lockdowns, while demand for electronic components would continue to rise causing a sort-of combined effect of the bullwhip and ripple effects. This combined effect caused mass shortages of essential components such as semiconductors.

As of mid-2021, the COVID pandemic is no longer seen as the primary disruptive event affecting resource capabilities. The constant shortages of essential parts continue to plague the automotive industry. However, the future looks bright, and with continued technological advances, the SC of the automotive industry should recover within the next year or two, given no other massive black swan events occur.

Two themes were missed in the literature review that was brought up in the data results. First, was the semiconductor shortage of 2021. Since the shortage is a very recent phenomenon that only dates back a few months, there were no solid academic journals that were found describing the shortage in detail. However, the semiconductor shortage of 2011 was included in the literature review by Park et. al.

The second missing phenomenon was the bottleneck effect. Although operational risks were briefly touched upon in multiple journals by prominent researchers, such as Ivanov, the actual bottleneck effect was not written about in those papers.

Level 3: Second Research Question

- **Which disruptive risk mitigation strategies have been implemented and how have they affected firms' operational capabilities?**

  A mix of proactive and reactive risk mitigation strategies were found to be the most effective in sustaining optimal operational capabilities. Careful strategic decisions need to be considered when balancing cost and risk. The following strategies helped keep firms' operational capabilities viable.

Forecasting models, which indicates inventory needs, were found to be the most common and effective proactive strategy that has been implemented against disruptive events, including the pandemic.

These forecasting methods should have a digital twin attached to it, with the use of advancing technology, such as AI IoT implemented within the model.

Black swan events are a huge obstacle to creating a fully effective predictive model since these events cannot be foreseen.

The end goal is to create a transparent SC. Hence why suppliers must build trusting relationships with their sub-suppliers in order to obtain live data.

There were three individual reactive strategies to fight disruptive events that were found:

1. Having multiple suppliers is preferred over single-sourcing. However, there are supplies, like semiconductors, where only single-sourcing is available.

2. JIT is preferred due to cost-efficiency. However, the pandemic has taught that it is a good idea to have some safety stock available, by weighing the cost of extra inventory to the cost of potential supply shortages.

3. Crisis task forces have been proven to be very effective in fighting disruptions caused by COVID-19. SC crisis teams are set up and split into sub-divisions based on different operating functions, such as production and purchasing.

There was one missing theme that was not found within the literature review, the use of crisis teams as a reactive strategy was not mentioned. However, crisis teams were found in some literature found in §2, such as the journal by Sheffi, which described the importance of having your team trained in the knowledge of backup emergency processes. in case there is a damage to the systems (p. 4, 2001).

One major discrepancy found in the literature review that did not match the data results was the use of RFID chips. Both Asif & Mandviwalla and Angeles wrote of the high use of RFID chips in the automotive industry. However, both these papers were published in 2005, and therefore, the literature is outdated, since Respondent 6 stated that they were not commonly used.

Level 4: Follow-up Question

- **How is the future of SC in the first-tier automotive industry predicted to look in the years following the pandemic?**

There is an accelerated demand for electronic components due to the changing market towards electric and autonomous cars. There are many new start-ups in electric vehicle manufacturing competing with older well-known companies. Car sharing services might become more focused on hygienic measures, such as the use of UV light germ detection in taxis.

The pandemic taught the industry about disruptive risk management. The use of data-driven methods, such as digital twins, as a proactive strategy needs to be implemented. Through R&D, the power of AI IoT will greatly improve simulation models.

An increase in both regional multi-sourcing and safety stocks should be implemented strategically, still allowing for global sourcing and JIT capabilities as reactive strategies to balance both cost efficiency and risk management.

6. Conclusion

This thesis concludes with a contribution to both practical and theory research, future research opportunities, and limitations that were reached.

6.1. Contribution to Practical Research

The automobile industry, including the first-tier automotive sector, and their disruptive SC risk mitigation strategies that have been implemented have been previously researched extensively. However, no disruption in modern history has ever had such a large impact on the SC of every global industry. Due to this new and impactful event, research needed to be conducted to understand the implications of risk mitigation strategies that were in effect during COVID-19. It was imperative to find solutions to this prominent problem since the automotive industry in one of the largest global industries. This thesis found, through multiple interviews with key players, how the disruptive SC risk mitigation strategies implemented by major first-tier automotive suppliers within their SC have impacted the firms' operational capabilities. This research has identified how these strategies will evolve after COVID-19, as well the future of digitalization within the automobile industry.

6.2. Contribution to Theory Research

This thesis has clearly demonstrated that the ripple effect impacts the supply of products available within the SC, thus increasing supply risk. The bullwhip effect was shown to affect the demand of products, thus increasing demand risk. This study has illustrated that the ripple effect causes the bullwhip effect and leads to operational risks, such as the bottleneck effect.

6.3. Limitations

The primary research gathered through interviews primarily focuses on German managers. Unfortunately, due to cultural differences and physical distance, the representatives of the East Asian market, mostly Japan, and the North American market, primarily the US, were unable to participate in the interview process. Therefore, although this thesis does have a global mindset, the data collected is still predominantly European.

Another limitation to this research was the restriction on the amount of words limited to this thesis. If this thesis were to be written as a longer dissertation, then the actual financial outcomes could have been compared to the operational capabilities through quantitative methods. These findings would have provided a clearer image of the successfulness of SC risk mitigation strategies of first-tier automotive suppliers.

The third limitation is a time limitation. There is insufficient time elapsed since the beginning of the pandemic to truly see the operational outcomes. Although the worst of pandemic (hopefully) is over, the effects are still being felt through shortages of supplies. How this will play out over the next few months is still unknown.

6.4. Future Research

This thesis primarily focused on operational capabilities of first-tier automotive suppliers. Future research can be conducted on the SC risk management strategies implemented within other industries, such as the aerospace, entertainment, and communications industries. How the pandemic affected aeroplane, TV, and mobile phone supplies, for example, was not touched upon. A focus on second and third-tier automotive suppliers is another future research aspect that can be conducted. Researching how raw material producers were impacted by COVID-19 and why these firms do not want to share information to increase transparency would be of great interest towards finding the best risk mitigation strategies for the entire automotive industry. The operational capabilities of first-tier automotive manufacturers can be researched in the next few years to see how the semiconductor shortages span out and if the predicted future outcomes have occurred.

In conclusion, SC risk mitigation strategies within the automotive industry were truly put to the test in the past year and a half. Some changes in strategy are highly likely to occur, such as an increase in regional sourcing. The rapid change towards electric cars over the next few years is bound to change the automotive landscape and their mitigation strategies once again. Hopefully another black swan event, such as COVID-19, does not occur again for a long time in order for the automotive industry, and every other global industry for that matter, to restrengthen itself and continue growing.

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Appendix

Appendix A: Thematic mentions within the literature review sources.

54 academic journals, case studies and books were used as secondary sources for the completion of the literature review (§2). 8 more academic sources were used to describe the methodology (§4). Some of the sources apply to multiple themes, however, only the most prominent theme was used per source from §2 in this chart:

Theme	Author, Year (# of mentions)
First-tier automotive SCRM	
Structure of SC	Aoki & Lennerfors, 2013 (1); Childerhouse et. al, 2003 (2); Cukrovic et. al., 1999 (1); Mahoney & Pandian, 1992 (1); Messina et. al, 2015 (2)
Risk Types	Beaver, 1966 (1); Blos, 2009 (1); Manuj & Mentzer, 2008 (4); Spekman & David, 2004 (2); Srivastava & Rogers, 2021 (1); Tang & Musa, 2010 (1); Wernerfelt, 1984 (1)
Viability within SC	Aubin, 1991 (1); Beer, 1984 (1); Graham & Hardaker, 2000 (1); Ivanov, 2018 (2). Ivanov, 2020 (3); Lee J et. al, 2002 (1); Spiegler et. al, 2012 (1)
Complexity within SC	Basole, 2014 (1); Holt, 1955 (1); Ivanov & Dolgui, 2020b (3); Katsaliaki et. al, 2021 (1); Liao et. al, 2010 (1); Niu et. al, 2018 (1)
Former Disruptive Events	
Disruptive Events	Cariappa et. al, 2020 (1); Mahajan & Tomar, 2020 (1); Park et. al, 2013 (1); Paul & Chowdhury, 2020 (1)
Ripple Effect	Dolgui et. al, 2017 (2); Ivanov, 2017a (1); Ivanov et. al, 2018 (1)
Bullwhip Effect	Ivanov, 2017b (3); Ivanov & Schönberger, 2019 (2); Lee H L et. al, 1997 (2)
Proactive Strategies	
Forecasting	Goodfellow et. al, 2015 (1); Nikolopoulos et. al, 2020 (4); Nsoesie et. al, 2013 (2); Wichmann et. al, 2020 (3)
Digital Twins	Ivanov & Dolgui, 2020a (4); Khajavi et. al, 2019 (2)
Newer Technologies	Angeles, 2005 (1); Asif & Mandviwalla, 2005 (1); Özdemir & Hekim, 2018 (1)
Reactive Strategies	
Multiple Suppliers	Nuñez, 2006 (1); Pries, 1999 (2); Shefi, 2001 (3); Thun, 2009 (2); Wagner et. al, 2008 (1)
JIT vs. Safety Stocks	Aksoy & Öztürk, 2011 (1); Chopra & Sodhi, 2004 (3); Hudin & Hamid, 2015 (1); Hudson & Sadler, 1992 (1), Turnbull, 1988 (1); Zsidisin et. al, 2000 (1)
Proactive & Reactive	Craighead et. al, 2007 (2); Dani, 2009 (3); Shao & Dong, 2012 (1)

Appendix B: Interview Questions

Semi-structured Interviews:

1. What is your position within the firm? *(level 1)*
2. How is your supply chain designed? *(level 1)*
3. How did COVID-19 affect your supply chain? *(level 2)*
4. How have other past disruptive events affected your supply chain? *(level 2)*
5. Which proactive strategies are implemented against disruptive SC events and why? *(level 3)*
6. Which reactive strategies are implemented against disruptive SC events and why? *(level 3)*

…

7. What can be learnt from the pandemic and where do you think the future is headed for the first-tier automotive industry? *(level 4)*

Generally trying to find and analyze:

1. **Design of the SC**: sources and indirect members of ISN, complexity and viability of SC

2. **Theoretical effects** of COVID-19 and past/side disruptions

3. **Proactive Strategies:** speed and effectiveness of response and use of new tech.

3. **Reactive strategies:** Use of multiple suppliers and back-up inventory vs. JIT

…

4. **What was learnt:** important takeaways of SC and risk mitigation strategies, future implications

Level 1: formal definitions and statistical measures
Level 2: identify problems of qualitative data
Level 3: connection of results to theory
…
Level 4: key takeaways

Appendix C.1: E-mail Interview Request

Master Thesis Interview Request

To [redacted] on 06.07.2021 22:47
Details HTML

Dear Ms. [redacted],

I'm writing as a Master's student in International Business and Law at Management Center Innsbruck (MCI) in Austria in regards to my thesis on how the pandemic affected first-tier automotive manufactures' supply chains. I want to find which risk mitigation strategies, if any, that managers used to fight potential disruptions caused along the supply chain and how effective such strategies were.

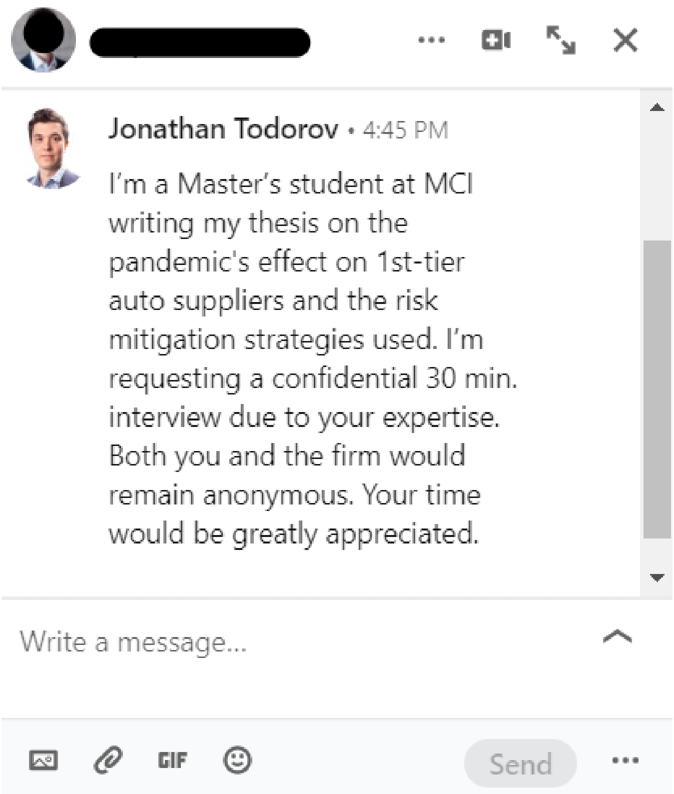
I'm contacting you to ask if we could set up a 30 minute interview online with a supply chain or logistics manager. Their input would be very beneficial to my research and I would really appreciate their time. The interview would be confidential and I wouldn't release anything without explicit permission.

If an interview can be set up, I'll be sure to keep you updated and, if you'd like, can include your company name in my thesis. If there's anything else I could do for you in exchange for your knowledge and time I'd be happy to oblige.

Looking forward to your response,

Jonathan Todorov

Appendix C.2: LinkedIn Message Interview Request



Appendix D: Consent Form

MCI ethics assessment consent form

TO BE SIGNED / ACCEPTED BY STUDY PARTICIPANTS

I understand that my participation in this study will involve:

An online interview by means of Microsoft Teams

and that this will in total require approximately **30** minutes of my time.

I understand that the whole or some parts of the study might be audio/video recorded.

I understand that the recorded data will be made anonymous and be accessible to a small team of researchers for study purposes.

I understand that even though the recorded data will be made anonymous it will not be available to other people outside of the mentioned research team.

I understand that participation in this study is entirely voluntary and that I can withdraw from the study at any time without giving a reason. I understand that in case I withdraw from the study, all the data that has arisen from my contribution will be removed unless it has already been disseminated (e.g. unless it has already been published).

I understand that I am free to ask any questions at any time. I am free to withdraw without providing a reason, or to discuss my concerns with the interviewer.

I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.

I understand that I can make subsequent contact with the leading researcher if I wish to obtain a copy of any publications derived from the research.

I understand that the information provided by me will be held anonymously so that it is impossible to trace this information back to me individually.

I,……………………………………………………………………………consent to participate in this study conducted by

………Jonathan Todorov…………… under the supervision of …………Dr. Oliver Som……….

Jonathan Todorov

……………………………………………………………………… ……………………………………………… ……………………

Signature of study participant

Signature of lead researcher
(Student in case of Bachelor/Master thesis)

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Appendix E: Full Interview Transcripts

The transcripts document is located in "MTTranscripts", found in the folder attached to this thesis.

The actual transcripts were not included in this document due to the high number of pages.

Below is a chart indicating exactly which pages belong to which interview. To open the transcripts click the hyperlink MTTranscripts

Interview	Firm	Transcript Pages
I1	Firm A	1-7
I2	Firm B	8-15
I3	Firm C	16-22
I4	Firm D	23-31
I5	Firm E	32-40
I6	Firm F	41-51
I7.1/I7.2	Firm G	52-64

Deceleration in Lieu of Oath

"I hereby declare, under oath, that this master thesis has been my independent work and has not been aided with any prohibited means. I declare, to the best of my knowledge and belief, that all passages taken from published and un-published sources or documents have been reproduced whether as original, slightly altered or in thought, have been declared as such at the correspondence places of the thesis, by citation, where the extent of the original quotes is indicated.

This paper has neither been submitted for evaluation to another examination authority nor has been published in this form or another."

Innsbruck, AT, 10.09.21

Jonathan Todorov