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An Ability to Survive Disruptions: Findings from Three Finnish Manufacturing Companies' Supply Challenges during the COVID-19 Pandemic

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Being multinational and complex, global supply chains may be extremely vulnerable to sudden crises, such as the recent COVID-19 pandemic. In addition to issues related to the health and lives of people, the pandemic has also had negative impacts on supply chains, and many companies dependent on them have been struggling. The ability to recover from disruptions is called resilience. In this study, the resilience of supply chains is evaluated by studying three globally operating Finnish B2B manufacturing companies during the COVID-19 pandemic. The empirical research was conducted by interviewing the companies' supply chain and purchasing operations representatives, analysing the results and comparing the results to the literature. As a result, essential methods to survive during crises and increase the resilience of supply chains were discovered. The results can be utilised in preparing for future crises.

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Introduction

In 2020, the world faced a huge disruption in the form of the COVID-19 pandemic. COVID-19 affected the lives and health of people, but also had direct and indirect effects on companies because of restrictions, lowering consumption or stalling economies, which directly affected global trade (Kraus et al. 2020; Wilding, Dohrmann, and Wheatley 2020). As a preventive action, many businesses and factories were closed during the pandemic (Rio-Chanona et al. 2020). Negative effects have also been recognised in the global economy, industries and individual businesses,

politics, the way we live and interact, and supply chains around the globe (Wilding, Dohrmann, and Wheatley 2020). This has caused disruptions in the operations of companies because most industries depend on global supply chains (Kraus et al. 2020).

The global coronavirus pandemic has not been the only crisis in modern history (Giansoldati and Gregori 2018; Kraus et al. 2020; Manuj and Mentzer 2008). For example, before COVID-19, one of the most-studied severe crises was the Fukushima disaster (Matsuo 2015; Park, Hong, and Roh 2013; Todo, Nakajima, and Matous 2014). Usually, disruptions such as natural disasters or terrorist attacks have brought changes to operations, safety or other issues of companies (Gibb and Buchanan 2006); sudden natural disasters have especially shown the vulnerabilities of supply chains (Manuj and Mentzer 2008).

The risk management of supply chains has been studied (Jüttner, Peck, and Christopher 2003; Manuj and Mentzer 2008; Tang 2006), but in the current study the context is the COVID-19 pandemic-the longest-lasting and most severe crisis this century. Studies on supply chain resilience in the COVID-19 context are emerging (Belhadi et al. 2021; Golan, Jernegan, and Linkov 2020; Ivanov and Dolgui 2020; van Hoek 2020) and studies on the pandemic and its influences on different types of businesses, such as family businesses (Kraus et al. 2020) and small businesses (Bartik et al. 2020) exist, but there is a need for further research in different geographical areas, industries and specific functions, such as supply chain management. Finland has a unique geographical position: a remote location from its main markets (Ministry of Transport and Communications Finland 2005) and a strong trade and export orientation, with international trade accounting for a third of its GDP (International Trade Administration 2020). Thus, the country is strongly dependent on the global economy. In addition, Finnish companies greatly depend on global supply chains.

The present study aims to increase the scientific knowledge on managing the vulnerabilities in supply chains and on surviving disruptions in the global manufacturing industry. We focus on the supply operations of three globally operating Finnish B2B manufacturing companies. To support the aims of the current study, the following research questions are posed:

RQ1 *What kinds of vulnerabilities and disruptions were identified in the supply chain operations of the studied companies?*

RQ2 *What were the key methods to cope with these vulnerabilities and disruptions?*

The present study is qualitative and includes both literature and empirical analyses. The data collection took place during 2020 and thus the COVID-19 pandemic formed the context for the study, but the study focused also on generic vulnerabilities of the case companies' supply chains. The first section includes the study's background, objectives and research questions. The second section presents related literature, that is, supply chain risk management and supply chain resilience (SCRES). The third section describes the research methods, and the fourth section presents the results. The fifth section includes the discussion, with the conclusions being presented in the sixth section.

Literature Review

Many companies operate globally because of opportunities for high specialisation, wider market area, labour and material costs, tax abatements or having an interest in international product, capital or factor markets (Manuj and Mentzer 2008). Companies may also have unique abilities to manufacture certain products, thus being able to generate international demand (McMillan 1990). To meet this demand, goods are usually produced and delivered through supply chains; sociotechnical networks to identify, target and fulfil a certain demand; a process to decide what, when and how much should be moved where (Davis 1993); or the management of supplies, suppliers, inventory and distribution (Goffin, Szwejczewski, and New 1997). Global supply chains require highly coordinated flows of goods, information, cash and services (Manuj and Mentzer 2008), making them vulnerable to disruptions and highlighting the importance of managing risk and resilience.

RISKS OF SUPPLY CHAINS

Global supply chains and networks may be extremely vulnerable because of the growing interdependence of companies (Tukamuhabwa et al. 2015), longer paths and shorter clock speeds and overall complexity, all of which can increase the probabilities for disruptions and create smaller error margins (Kleindorfer and Saad 2005). Thus, one disruption may affect and lower the capacity of the entire supply chain (Manuj and Mentzer 2008).

Supply chain risks have been divided into specific categories: low-impact and high-impact risks (Simchi-Levi, Schmidt, and We 2014),

TABLE 1 Business-Related Risk Factors

Risk(s)	Author(s)
Poor supplier performance, reliability and logistical risks	Manuj and Mentzer (2008) Simchi-Levi, Schmidt, and We (2014)
Forecast errors and challenges in coordinating supply and demand	Christopher and Lee (2004) Simchi-Levi, Schmidt, and We (2014)
Obsolescence	Christopher and Lee (2004) Manuj and Mentzer (2008)
Inadequate availability of materials and components, stock-outs, overstocking, precision of the components and materials and lack of accuracy	Manuj and Mentzer (2008)
Increased dependency of IT networks, human errors and utility disruptions	Cerullo and Cerullo (2004)
Uncertain economic cycles and customer demands, JIT (just-in-time)	Tang (2006)
Hidden risk	Simchi-Levi, Schmidt, and We (2014)

TABLE 2 High-Impact Risks

Risk(s)	Author(s)
Natural disasters, political upheavals and strikes	Cerullo and Cerullo (2004) Kleindorfer and Saad (2005) Manuj and Mentzer (2008) Simchi-Levi, Schmidt, and We (2014)
Terrorist attacks	Cerullo and Cerullo (2004) Kleindorfer and Saad (2005) Tukamuhabwa et al. (2015)
Economic disruptions	Kleindorfer and Saad (2005) Manuj and Mentzer (2008)
Competitive and infrastructure risks	Manuj and Mentzer (2008)
Factory fires	Simchi-Levi, Schmidt, and We (2014)
Changes in enterprises	Gibb and Buchanan (2006)

quantitative and qualitative risks (Manuj and Mentzer 2008), external or natural and man-made risks (Tukamuhabwa et al. 2015; Tang 2006) or risks related to disruptions in normal activities (Kleindorfer and Saad 2005). The risks related to businesses are presented in table 1, whereas the high-impact risks are presented in table 2.

Poor supply and demand coordination (Christopher and Lee 2004;

TABLE 3 Risk Mitigation Tools

Risk mitigation tools	Author(s)
Excessive inventories and inventory management	Christopher and Lee (2004) Kraljic (1983) Simchi-Levi, Schmidt, and We (2014) Tukamuhabwa et al. (2015)
Operating with multiple manufacturing plants and production lines	Kraljic (1983) Simchi-Levi, Schmidt, and We (2014)
Relocating inventories, sourcing and production lines	Wilding, Dohrmann, and Wheatley (2020)
Supplier selection, building logistics capabilities, risk management culture, supply chain collaboration, supply network structure and visibility	Tukamuhabwa et al. (2015)
System flexibility, strategic partnering with suppliers, long-term contracts with penalty clauses and using standardised components on product structures	Simchi-Levi, Schmidt, and We (2014)
Manufacturing multiple products	Kraljic (1983)

Simchi-Levi, Schmidt, and We 2014) may lead to a bullwhip effect, which may distort the actual product demand. Here, a ripple effect is the impact of disruption propagation through a supply chain (Dolgui, Ivanov, and Sokolov 2018). Hidden risk (Simchi-Levi, Schmidt, and We 2014) means that the total spending on the supplier is relatively low, but the risk's financial impact is high. Changes in operations, such as automation, downsizing, process re-engineering or outsourcing may also introduce new risks (Gibb and Buchanan 2006).

Supply chain risks have traditionally been managed by evaluating the magnitude and likelihood and business impacts of risks and locations, and configuration of technological assets (Simchi-Levi, Schmidt, and We 2014). Wilding, Dohrmann, and Wheatley (2020) state that it is important to know where the suppliers of all tiers are located. The risk potential of traditional events may be evaluated by using historical data, but it is hard to predict high-impact risks that have a low probability of occurring (Simchi-Levi, Schmidt, and We 2014). Supply chain risks can be mitigated by transferring them through insurance and outsourcing, or minimising, reducing, eliminating, absorbing or avoiding them (Gibb and Buchanan 2006). The risk mitigation tools are presented in table 3.

Although excessive inventories and inventory management are often mentioned (Christopher and Lee 2004; Kraljic 1983; Simchi-Levi, Schmidt, and We 2014; Tukamuhabwa et al. 2015), Christopher and Lee (2004) add that supply chain risk mitigation methods may lead to financial risks because of obsolete inventory.

RISKS IN SUPPLY OPERATIONS

Supply operations and supplier management may be a significant competitiveness factor, particularly if a company relies a lot on supplied materials and components (Goffin, Szwejczewski, and New 1997; Kraljic 1983). Good suppliers may also help in new product development, and through achieving better delivery performance through process development (Goffin, Szwejczewski, and New 1997; McMillan 1990), supply security can be improved (Kraljic 1983). Thus, suppliers may have a huge influence on a company's success or failure (Goffin, Szwejczewski, and New 1997).

Regarding supply strategies, single sourcing, the reduction of the supplier base and long-term supplier relationships have been preferred in manufacturing to effectively manage suppliers, increase quality and obtain economic benefits (Goffin, Szwejczewski, and New 1997; McMillan 1990). However, single sourcing is a risk (Wilding, Dohrmann, and Wheatley 2020); here, dual or multisourcing methods are usually preferred to mitigate supplier risks (McMillan 1990; Simchi-Levi, Schmidt, and We 2014). Alternative options also exist, such as single sourcing with back-ups (Goffin, Szwejczewski, and New 1997) to enable the benefits of having few suppliers while reducing risks. Another popular approach is the just-in-time (JIT) method, which requires only a few suppliers that are located close to the buyer's plant, close cooperation and frequent deliveries (Gunasekaran 1999).

The focus of supplier risk mitigation is usually on the suppliers of the strategic components that often depend on a single supplier (Simchi-Levi, Schmidt, and We 2014). The preferred and available sourcing strategies depend on power relations (Kraljic 1983). When buyers are stronger, the strategies may include reducing their own inventories, spot buying and minimising logistics costs. In the case of equality, the operations include optimising and balancing and buffer stocks. If the supplier is stronger, the supply is ensured by contracts.

Business continuity management (BCM) is an enterprise-wide approach to risk identification, mitigation and recovery (Gibb and Buchanan

2006); it relates closely to supply risks and resilience. As a tool to deliver products despite crises (Gibb and Buchanan 2006), BCM includes a risk analysis, selection of mitigation strategies, monitoring and control, implementation, testing, education and training, and review (Cerullo and Cerullo 2004; Gibb and Buchanan 2006; Lam 2002). Cerullo and Cerullo (2004) highlight the importance of testing and training employees to reveal the vulnerabilities of the continuity plan and increase employee performance during disruptions.

SUPPLY CHAIN RESILIENCE

SCRES refers to a supply chain's ability to recover from a disruption and move either back to the original or a totally new state (Pettit, Croxton, and Fiksel 2019; Ponomarov and Holcomb 2009). Here, resilience is the ability to survive, adapt and grow in the face of crises, and it consists of two factors that need to be balanced: vulnerabilities and capabilities (Pettit, Croxton, and Fiksel 2013). Tukamuhabwa et al. (2015, 5599) concisely define SCRES as: 'The adaptive capability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations-ideally, a better state than prior to the disruption.' SCRES may be vital for immediate survival (Cerullo and Cerullo 2004), but it is also critical as a source of a long-term competitive advantage because a proper response to a disruption may improve a company's market position (Tukamuhabwa et al. 2015).

A resilient supply chain should be flexible because the new state may differ from the original state (Ponomarov and Holcomb 2009), and its elements may change in response to a disruption (Tukamuhabwa et al. 2015). When it comes to recovering, supply chains should have the capabilities to anticipate, monitor, respond and learn (Hollnagel 2009), the latter of which will tend to result in increased SCRES (Tukamuhabwa et al. 2015). However, flexibility may also incur costs. Indeed, Jüttner, Peck and Christopher (2003, 203) mention: 'Flexibility is often sacrificed for cost reduction.' Jüttner and Maklan (2011) state the possible threats related to SCRES, such as sharing sensitive information and using multisourcing strategies, which may lead to liquidity risk. If excessive amounts of resources are used to mitigate irrelevant risks, the profits of the company may be eroded (Pettit, Croxton, and Fiksel 2013). Additionally, Baghersad and Zobel (2021) find that larger firms are more resilient to supply chain disruptions than smaller firms because they tend to be able to absorb the

TABLE 4 Identified SCRES Capability Factors

SCRES capability factor	Description
Supply network structure	The structure is the most suitable for the operations and supply chain environment. Operations are dispersed to many factories and production lines (Kraljic 1983; Simchi-Levi, Schmidt, and We 2014; Wilding, Dohrmann, and Wheatley 2020).
Visibility, speed and flexibility	The visibility enables real-time actions if crises occur. Changes can be made quickly to enable recovery (Cerullo and Cerullo 2004; Tukamuhabwa et al. 2015), and structures are flexible to adapt and enable changes in supply chains (Ponomarov and Holcomb 2009; Tukamuhabwa et al. 2015).
Resilient practices in supply operations	Resilience is built, for example, by choosing the right suppliers and suitable supply methods (Goffin, Szwejczewski, and New 1997; McMillan 1990), with increased inventory levels and buffers (Christopher and Lee 2004; Kraljic 1983; Simchi-Levi, Schmidt, and We 2014).
Collaboration	Effective communication and collaboration in the supply chain with all the stakeholders, mutual objectives and sharing knowledge related to supplied items and processes (Tukamuhabwa et al. 2015).
Culture of resilience	Building preparedness by mitigation strategies and plans, recovery practices, simulations and personnel trainings (Cerullo and Cerullo 2004; Gibb and Buchanan 2006; Tukamuhabwa et al. 2015).

risks because of more resources, whereas smaller firms may be more agile and recover faster.

This literature review can be summarised as a set of the key capability factors of SCRES and their definitions. They are presented in table 4 and are used as the basis of the empirical part of the research presented in the next sections.

Research Process

A case study method was utilised in the current research; it is a useful method when studying contemporary phenomena that cannot be affected by the researcher and looking at these phenomena in a broad context (Yin 2003). Based on the literature review presented in the second section, a semistructured interview guide (Appendix 1) was created to understand the general practices, patterns of material and information flows and the current practices of managing vulnerabilities and disruptions of three case companies. From each of these three globally operating manufacturing companies, key persons related to supply chain operations

TABLE 5 Case Companies and Interviewees

Company	Revenue	Personnel	Industry	Roles of the interviewed
Company 1 (C1)	>2 billion €	>10,000 in more than 40 countries	Maritime, Defence and Aerospace, and Digital	Development manager, Operative purchaser, Sourcing manager, Strategic purchaser, and Supply chain manager
Company 2 (C2)	>500 million €	>3,000 in several countries	Electronics, contract manufacturer	Value chain director and Material and logistics manager
Company 3 (C3)	>3 billion €	>15,000 in more than 50 countries	Fluid engineering and related technologies	Category specialist, Logistics manager, Operative purchaser/Workflow manager, Purchasing manager, and Operative purchasing manager

(table 5) were interviewed. The interviewees had the opportunity to familiarise themselves with the interview guide beforehand. The interviews were transcribed and then analysed to identify key concepts and issues, commonalities and juxtapositions.

Results

The interview findings were categorised according to the SCRES capability factors presented in table 4. Abbreviations C1, C2 and C3 are used to indicate the companies described in table 5.

SUPPLY NETWORK STRUCTURE

All the case companies have global supply networks, and one common supply location is China. Additionally, domestic and Italian suppliers are preferred by C1, whereas C3 is sourcing globally, mostly from Europe, South Korea, India and the USA. All transportation modes are used (C1, C3), but C2 prefers air freight. The transportation mode used varies depending on location, urgency, price, lead time and the type of component (C1). Air freight availability and the high price were identified as challenges during the pandemic (C2, C3). Some air transportations were shifted to rail and road (C2), but C1 had disruptions even in train deliveries because of closed borders.

Multiple-tier supply chains and long lead times were considered vulnerabilities because of decreasing visibility (C1, C3). For example, C3's supply chain may consist of up to four tiers of suppliers, making the network very complex. Failures in critical engineered components with long manufacturing times were considered risks (C1, C3). C1 had recognised the disruptions related to material shortages, machine breakdowns, transportation disruptions and the financial challenges of suppliers.

VISIBILITY, SPEED AND FLEXIBILITY

Visibility was seen as important, and it was evident that a lack of visibility exists in supply chains. Challenges existed in obtaining real-time logistical information (C1, C2, C3), which was seen as a potential risk because of slower reactions to sudden changes (C1, C2). For example, GPS tracking of train deliveries (C1) was used, but in most cases, 'information was only received if the arrival times changed or shipments were stuck' (C1). The problems were usually investigated manually if the goods did not arrive on time (C2). C3 used a manually updated shared folder with the logistics operators and purchasers to track deliveries. However, real-time information was not available.

Deliveries were often confirmed manually, and after that, the companies did not have the visibility or capabilities to track the state of the purchase orders (C1, C2); however, C3 used mostly automatic confirmation, and C2 had a goal of shifting from manual to automatic order confirmation. Pilot projects were also conducted to increase the visibility in the supply network and improve traceability (C2, C3). C2 saw that 'better visibility would enable more realistic delivery schedules and changes in them.' Another solution for better real-time visibility was the integrated services of logistics providers (C2).

Database interfaces and electronic data interchanges (EDIS) were used between the suppliers and buyers in the cases of C1 and C3 to manage the order log, confirm the orders and provide real-time information related to orders, but with smaller suppliers, the purchase orders and confirmations were done via e-mail and confirmed manually in the Enterprise Resource Planning system (ERP). However, changes in purchasing orders were not possible for C1, and any changes had to be done via e-mail or phone. In particular, C1 and C2 used a lot of manual data transfer by Excel sheets, even though C1 had recognised information distortions related to this. C1 sent some purchase orders via ERP, but an automatic system to send purchase orders did not exist. Challenges also existed when

it came to getting the purchase requests at the right time through the ordering process to meet the demand (C3).

C1 achieved speed by using instructions and checklists to consider the required actions and sharing responsibilities. C1's crisis management team had mandates to appoint a recovery team consisting of key management team members. The importance of flexibility among suppliers was addressed to rearrange production plans and lead times and find new supply options to ensure continuous material flows during disruptions. The inflexibility of logistics partners was recognised as a challenge in deliveries (C3).

RESILIENT PRACTICES IN SUPPLY OPERATIONS

To mitigate risks critical components' delivery, stock buffers were built for certain suppliers (C1) and risky regions (C2), but there were also strategic alignments made for reducing inventory levels (C3). Higher inventory costs were covered by a service fee from customers so that faster lead times could be provided (C2). The risks related to late deliveries were mitigated by having materials delivered in advance before production (C3).

Single suppliers were not usually preferred (C1, C3), except when it came to C2, which had some reactive backup options, such as spot purchasing and higher payments for suppliers. Other companies, such as C3, were using spot purchasing only on rare occasions. The purchasing volumes of C2 were low, and a majority of components were purchased from distributors.

Single sourcing vulnerabilities were recognised, especially if the products were tailored, the supplier had intellectual property rights (IPR) related to the products (C1), or the customers demanded using the components of a certain supplier (C2). IPRs prevented other manufacturers from manufacturing certain items, and the demand for using certain suppliers limited the selection of suppliers. The supply practices of the companies with several business units varied; for example, C3 had no strategic alignments for using certain suppliers or components companywide.

C1 typically used two to three suppliers per component, whereas the number of suppliers of C3 varied between one and five. C2 and C3 aimed to reduce the suppliers of some components. If many suppliers for a certain component existed and the needs for those components varied, purchases were usually split (C3). If customer demand suddenly increased, finding sufficient capacity was usually challenging.

Besides multisourcing (C1, C3), the companies prepared for disrup-

tions by having a wide supplier base (C3), geographical dispersion between suppliers, active communication and building better relationships with the suppliers (C2, C3), audits at the suppliers to discover and solve challenges together (C3), purchase contracts, and a continuous evaluation of current and new suppliers (C1, C3). If there were disruptions in the supply, alternative options were immediately looked for (C3). For example, C2 used local contact persons in foreign countries to visit the sites and look for optional supply sources. The evaluation of suppliers was seen as important because of quality challenges and safety issues. 'Poor quality components can sometimes lead to temporary sales bans or significant penalty fees' (C3). In addition, C1 had experienced late deliveries related to subsupplier disruptions. Overall, product complexities vulnerable to many defects were detected (C3).

Long-term partnerships were preferred by C1. Specific terms were used in the contracts to force suppliers to deliver confirmed orders in all circumstances (C2, C3), and 'better service was ensured by frame agreements with higher costs' (C2). Component refilling methods, such as Kanban, were used in C1 and C2 to automatically fill some needs.

COLLABORATION

Cooperation with customers was carried out to ensure sufficient capacity of subsuppliers (C1, C2 and C3), but C3 highlighted that clear and transparent communication with customers, especially in a moment of uncertainty, was challenging. C2 had also faced challenges in communication related to the inaccurate forecasts provided by customers, which led to relatively high inventory levels. Performance levels and risk mitigation procedures were actively presented to customers to create trust and visibility, but customers also inquired about the supplier risks and supply continuity (C2).

Supplier cooperation was exercised to solve supply challenges (C1). It was common for larger suppliers to inform the companies immediately about the changes, whereas smaller suppliers communicated changes later (C3). Joint weekly reviews of the supply issues were performed to enable efficient information sharing, and urgency and severity measurements were executed and communicated within the organisations globally (C3). Active communication, supplier evaluations and audits were generally recognised as important activities (C1, C2 and C3), especially with problematic and risky suppliers. C1 considered quality and delivery reviews as important. C3 had outsourced some manufacturing processes, and some challenges related to communication were identified.

CULTURE OF RESILIENCE

Risk reviews and mitigation plans were used to assess the risks in supply chains and prepare for them. The reviews included the financial reviews of suppliers, category reviews including single-source risk reviews and quality and delivery reviews. Simulations and regular exercises were conducted to test plans and preparation for unexpected scenarios and to provide useful feedback and improvement ideas, which was considered important for better readiness of the employees (C1). C3 was also randomly ordering excessive amounts of components on purpose to test the capacities of suppliers.

All companies used cross-functional crisis management teams, especially during the COVID-19 pandemic. Additionally, C3 had a small quality organisation for doing root-cause analysis of disruptive events and past crises and sharing the information to related functions. However, C3 did not have clear roles or defined structures for solving disruptions, whereas C1 had defined ownership of the actions and well-defined roles. C3 preferred frequent discussions between different functions during uncertain times and aimed to develop better disruption management structures.

C2 arranged crisis management team meetings on a weekly basis to inspect material availability of the factories, certain suppliers and affected customers, using an action list; in addition, the management of different factories communicated on a weekly basis the problems and current performance levels. C1 did not have common risk mitigation procedures with their suppliers, but they had some simple risk management procedures with logistics operators. The creation of recovery plans was considered challenging because disruption types vary and a plan that is too general is not useful (C1). C3 saw that there was a lack of strategic alignments that could enable better management of unexpected changes. C3's different business units operated independently without any clear assessment of vulnerabilities and mitigation plans. C1 also had plans to demand business continuity plans and risk evaluations from suppliers.

Discussion

KEY VULNERABILITIES AND DISRUPTIONS

Research on supply chain resilience in the context of COVID-19 is emerging (Belhadi et al. 2021; Golan, Jernegan, and Linkov 2020), and this study contributes by providing additional and geographic-specific information through real-life findings; a research gap identified by both Ivanov and

Dolgui (2020) and van Hoek (2020). The most common challenges related to supply chain vulnerabilities were related to a decreased availability of components, IT systems and lack of visibility, delivery challenges and long lead times. Some supplier factories were closed temporarily in risky regions at the beginning of the COVID-19 pandemic. Rio-Chanona et al. (2020) find the same issue, but according to our findings, some suppliers' capacities have decreased even in the long term. Some suppliers may have closed their operations because of low demand, but some may have shifted the production to more profitable goods or goods necessary for national security of supply. The findings also indicate price increases for engineer-to-order (ETO) components, which could be the case of a high-impact disruption, that is, COVID-19, triggering another major risk that affects global competition.

Our findings also show that the case companies suffered from inadequate IT systems, which did not enable real-time information sharing with the suppliers. Thus, supply disturbances were often not reacted to until the deliveries were late. This finding complements the results of Tukamuhabwa et al. (2015), who see the lack of visibility as a key supply chain risk factor. The studied companies had significant challenges in IT connections, which increased the need for manual data transfer. With better visibility and real-time information sharing, the companies could better anticipate and reconfigure the production schedules in time and give more realistic promises to customers, see e.g. Kauppila, Välikangas and Majava (2020).

Kleindorfer and Saad (2005) recognise that there is less room for errors because of longer supply chains and shortened clock speeds. Our results support this claim, especially with multitier supply chains. Besides increased prices, another rare effect was the decreased availability of air transportation. The limited availability and more expensive air freight affected the companies' costs and pricing. In some cases, customers accepted the price change but not in all cases. It was also found that some previously common components, such as electric motors and sensors, suddenly became critical.

It is interesting to note that these vulnerabilities all relate to business risks (table 1) that correspond to the risks presented by Manuj and Mentzer (2008), Simchi-Levi, Schmidt, and We (2014) and Cerullo and Cerullo (2004). This could be seen as an indication that the recognition of high-impact risks and building resilience has not yet been realised, despite the impact of COVID-19.

KEY METHODS FOR MITIGATING VULNERABILITIES AND DISRUPTIONS

Common solutions in the studied companies during disruptions included increased warehouse levels and buffer inventories, which have been recognised in several studies (Christopher and Lee 2004; Kraljic 1983; Simchi-Levi, Schmidt, and We 2014; Tukamuhabwa et al. 2015). Another method was to use multisourcing, which has also been discussed by McMillan (1990) and Simchi-Levi, Schmidt, and We (2014). The studied companies preferred to have three to five suppliers for one component, but this was considered challenging and expensive, and there were aims to reduce the number of suppliers. Using multisourcing may be expensive, especially for tailored components, because it leads to smaller batches and special set-up costs (McMillan 1990).

In our study, single sourcing, especially for critical components, was identified as a risk. This is also supported by Wilding, Dohrmann, and Wheatley (2020). Still, both multisourcing and increased warehouse levels may increase costs, and higher inventory levels may lead to obsolescence (Christopher and Lee 2004). On the other hand, a lack of certain components may shut production lines, which is an example of hidden supply risks (Simchi-Levi, Schmidt, and We 2014). Our study also identified a geographical dispersion in sourcing as a method to mitigate regional risks (Wilding, Dohrmann, and Wheatley 2020).

The studied companies also utilised crisis teams consisting of key persons from different functions, which is in line with the literature (Cerullo and Cerullo 2004; Gibb and Buchanan 2006). Frequent internal communication between different functions was used to ensure sufficient material flows between factories during uncertain times. Checklists, clear action plans and the well-defined roles of different employees were used for corrective actions during the disruptions. However, it was also identified that actions should be more proactive for better preparedness. The importance of training of the employees was identified in the results, which is also stressed by Cerullo and Cerullo (2004). In our study, simulations were identified to enable better preparedness to work during stressful situations and test and challenge action plans to find weaknesses, something that could be further emphasised in SCRES research. Building better relationships and close cooperation with different stakeholders in the supply chain, especially using vulnerability assessments that include the most important partners, were identified as important to improve the ability to

make real-time corrective actions during disruptions, which is similar to the findings of Simchi-Levi, Schmidt, and We (2014). Finally, it was seen as important to understand the capabilities of different suppliers. This relates to supplier management and supply network planning that can be identified as risk mitigation methods, as proposed by, for example, Tukamuhabwa et al. (2015).

Conclusions

Global supply chains have an inherent vulnerability to disruptions, as the COVID-19 pandemic has shown. In the current article, we studied the vulnerabilities and disruptions in supply chains of three Finnish B2B manufacturing companies and what types of methods can be used to address them.

Some common issues were identified in the analysis of the case companies' supply chains. These included decreased capacities of suppliers, increased vulnerability because of multiple supplier tiers or reliance on few suppliers and decreased responsiveness because of a lack of visibility in the supply chain. A noteworthy finding was not only that material flows were disrupted during the COVID-19 pandemic but that some suppliers' capacity seems to have decreased, even in the long term.

The most common methods to address the vulnerabilities and disruptions were increasing inventory levels for critical components, transferring from single- to dual- or multisourcing and decentralisation of the supply chain to mitigate country-specific disruptions. In addition, supplier collaboration was increased to share real-time information and identify common risks.

The results support previous research, yet the COVID-19 pandemic context also revealed unique vulnerabilities and disruptions. In terms of reliability and validity, the current study utilised the case study method, which results in some natural limitations in terms of the generalizability of the findings. Despite careful design, data collection, and analysis by multiple researchers, it must be noted that the study included only three companies in different industries and with different supply chains. Therefore, further studies are recommended to validate and compare the findings in different types of industries and companies. The research did not address systemically how the risks could be reduced in the case of a COVID-19 type of crisis, which could be a topic for further research. Another potential topic for further studies would be the use of more local and circular supply to improve resilience. Could resilience be improved

by replacing complex multinational supply chains with more effective utilisation of materials and local solutions?

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References

Baghersad, M., and C. W. Zobel. 2021. 'Assessing the Extended Impacts of Supply Chain Disruptions on Firms: An Empirical Study.' *International Journal of Production Economics* 231 (C). https://www.doi.org/10.1016/j.ijpe.2020.107862.

Bartik, A. W., M. Bertrand, Z. Cullen, E. L. Glaeser, M. Luca, and C. Stanton. 2020. 'The Impact of COVID-19 on Small Business Outcomes and Expectations.' *PNAS* 117 (30): 1765–6.

Belhadi, A., S. Kamble, J. S. C. Charbel, A. Gunasekaran, N. O. Ndubisi, and M. Venkatesh. 2021. 'Manufacturing and Service Supply Chain Resilience to the COVID-19 Outbreak: Lessons Learned from the Automobile and Airline Industries.' *Technological Forecasting and Social Change* 163:120447.

Cerullo, V., and M. Cerullo. 2004. 'Business Continuity Planning: A Comprehensive Approach.' *Information Systems Management* 21 (3): 70–8.

Christopher, M., and H. Lee. 2004. 'Mitigating Supply Chain Risk Through Improved Confidence.' *International Journal of Physical Distribution & Logistics Management* 34 (5): 388–96.

Davis, T. 1993. 'Effective Supply Chain Management.' *Sloan Management Review* 34 (4): 35–46.

Dolgui, A., D. Ivanov, and B. Sokolov. 2018. 'Ripple Effect in the Supply Chain: An Analysis and Recent Literature.' *International Journal of Production Research* 56 (1–2): 414–30.

Giansoldati, M., and T. Gregori. 2018. 'Trade Collapses and Trade Slowdowns: Evidence from Some Central and Eastern European Countries.' *Managing Global Transitions* 16 (1): 3–18.

Gibb, F., and S. Buchanan. 2006. 'A Framework for Business Continuity Management.' *International Journal of Information Management* 26 (2): 128–41.

Goffin, K., M. Szwejczewski, and C. New. 1997. 'When Fewer Can Mean More.' *International Journal of Physical Distribution & Logistics Management* 27 (7): 422–36.

Golan, M. S., L. H. Jernegan, and I. Linkov. 2020. 'Trends and Applications of Resilience Analytics in Supply Chain Modeling: Systematic Litera-

ture Review in the Context of the COVID-19 Pandemic.' *Environment Systems and Decisions* 40 (2): 222–43.

Gunasekaran, A. 1999. 'Just-in-time Purchasing: An Investigation for Research and Application.' *International Journal in Production Economics* 59 (1–3): 77–84.

Hollnagel, E. 2009. 'Prologue: The Scope of Resilience Engineering.' In *Resilience Engineering in Practice: A Guidebook,* edited by E. Hollnagel, J. Pariés, D. D. Woods, and J. Wreathall, xxix–xxxix. Farnhamn: Ashgate.

International Trade Administration. 2020. 'Finland – Country Commercial Guide.' https://www.trade.gov/knowledge-product/finland-market-overview.

Ivanov, D., and A. Dolgui. 2020. 'Viability of Intertwined Supply Networks: Extending the Supply Chain Resilience Angles towards Survivability.' *International Journal of Production Research* 58 (10): 2904–15.

Jüttner, U., and S. Maklan. 2011. 'Supply Chain Resilience in the Global Financial Crisis: An Empirical Study.' *Supply Chain Management* 16 (4): 246–59.

Jüttner, U., H. Peck, and M. Christopher. 2003. 'Supply Chain Risk Management: Outlining an Agenda for Future Research.' *International Journal of Logistics: Research and Applications* 6 (4): 197–210.

Kauppila, O., K. Välikangas, and J. Majava. (2020). 'Improving Supply Chain Transparency between a Manufacturer and Suppliers: A Triadic Case Study.' *Management and Production Engineering Review* 11 (3): 84–91.

Kleindorfer, P. R., and G. H. Saad. 2005. 'Managing Disruption Risks in Supply Chains.' *Production and Operations Management* 14 (1): 59–68.

Kraljic, P. 1983. 'Purchasing Must Become Supply Management.' *Harvard Business Review* 61 (5): 109–17.

Kraus S., T. Clauss, M. Breuer, J. Gast, A. Zardini, and V. Tiberius. 2020. 'The Economics of COVID-19: Initial Empirical Evidence on How Family Firms in Five European Countries Cope with the Corona Crisis.' *International Journal of Entrepreneurial Behaviour Research* 26 (5): 1067–92.

Lam, W. 2002. 'Ensuring Business Continuity.' *IT Professional* 4 (3): 19–25.

Manuj, I., and J. T. Mentzer. 2008. 'Global Supply Chain Risk Management.' *Journal of Business Logistics* 29 (1): 133–55.

Matsuo, H. 2015. 'Implications of the Tohoku Earthquake for Toyota's Coordination Mechanism: Supply Chain Disruption of Automotive Semiconductors.' *International Journal of Production Economics* 161 (C): 217–227.

McMillan, J. 1990. 'Managing Suppliers: Incentive Systems in Japanese and U.S. Industry.' *Californian Management Review* 32 (4): 38–55.

Ministry of Transport and Communications Finland. 2005. *Strengthening Finland's logistics Position: An Action Programme.* N. p.: Ministry of Transport and Communications.

Park, Y. W., P. Hong, and J. J. Roh. 2013. 'Supply Chain Lessons from the Catastrophic Natural Disaster in Japan.' *Business Horizons* 56 (1): 75–85.

Pettit, T. J., K. L. Croxton, and J. Fiksel. 2013. 'Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool.' *Journal of Business Logistics* 34 (1): 46–76.

———. 2019. 'The Evolution of Resilience in Supply Chain Management: A Retrospective on Ensuring Supply Chain Resilience.' *Journal of Business Logistics* 40 (1): 56–65.

Ponomarov, S. Y., and M. C. Holcomb. 2009. 'Understanding the Concept of Supply Chain Resilience.' *The International Journal of Logistics Management* 20 (1): 124–43.

Rio-Chanona, R. M., P. Mealy, A. Pichler, F. Lafond, and J. D. Farmer. 2020. 'Supply and Demand Shocks in the COVID-19 Pandemic: An Industry and Occupation Perspective.' *COVID Economics Vetted and Real-Time Papers,* no. 6, 65–103.

Simchi-Levi, D., W. Schmidt, and Y. Wei. 2014. 'From Superstorms to Factory Fires: Managing Unpredictable Supply-Chain Disruptions.' *Harvard Business Review* 92 (1–2): 96–101.

Tang, C. S. 2006. 'Perspectives in Supply Chain Risk Management.' *International Journal of Production Economics* 103 (2): 451–88.

Todo, Y., K. Nakajima, and P. Matous. 2014. 'How Do Supply Chain Networks Affect the Resilience of Firms to Natural Disasters? Evidence from the Great East Japan Earthquake.' *Journal of Regional Science* 55 (2): 209–29.

Tukamuhabwa, B. R., M. Stevenson, J. Busby, and M. Zorzini. 2015. 'Supply Chain Resilience: Definition, Review and Theoretical Foundations for Further Study.' *International Journal of Production Research* 53 (18): 5592–623.

van Hoek, R. 2020. 'Research Opportunities for a More Resilient Post-COVID-19 Supply Chain: Closing the Gap between Research Findings and Industry Practice.' *International Journal of Operations & Production Management* 40 (4): 341–55.

Wilding, R., K. Dohrmann, and M. Wheatley. 2020. 'Post-Coronavirus Supply Chain Recovery: The Journey towards the New Normal.' Deutsche Post DHL Group. https://www.dhl.com/global-en/home/insights-and-innovation/thought-leadership/white-papers/post-coronavirus-supply-chain-recovery.html.

Yin, R. K. 2003. *Case Study Research: Design and Methods.* 3rd ed. Thousand Oaks, CA: Sage.

Appendix: Interview Guide

Pre-assignment: please read these questions before the actual interview.

1 SUPPLY NETWORK

a Describe briefly what kind of structure you have in your supply chain.
b How does information move between these parts (e.g. how do you receive confirmations or status updates)? For example, by email, phone, website?
c Do you have bottlenecks in your information systems where data needs to be transferred manually?

2 INBOUND PROCESS

2.1 Procurement

a Describe briefly your sourcing model.
   - Which countries do you have sourcing from?
   - How many suppliers, on average, do you have per each component?
   - Do you have specific contracts (e.g. fixed-period contractual commitment to supply a certain amount of material with certain lead times and regularities)?
   - Do you have a backup supplier option? How do you keep low volume suppliers interested?

b Describe briefly your purchasing process (e.g. how do you send a purchasing order to a supplier?).
c How are the purchasing decisions made? What is the level of automation in purchasing decisions?
d What kind of system/practice do you have to keep track of the status of a purchasing order?
e What are the current challenges? What is your most critical component?

2.2 Inbound Logistics

a What mode(s) of transportation do you use? What are the lead times? Based on which factors is the mode of transportation chosen?
b Is your company responsible for organising the inbound logistics of the purchased materials?
   If yes, what kind of booking procedure/system do you have (e.g. do you have contractual 3rd party logistics providers, extranet booking system)? Do you plan the routing of logistics by yourself (e.g. preferred countries for customs clearance)?
   If not, can you choose the transport mode from the supplier based on e.g. price and lead time?
c How do you track the deliveries?
d What are the current challenges?

3 DISRUPTION

Disruption is a manifestation of a vulnerability, an unanticipated event, that harms the normal operational routines possibly affecting larger entity of a SC. For example, a truck breaking down, a supplier's workforce going on strike, a supplier going out of business or a pandemic affecting inbound material flow.

3.1 Disruption Mitigation Process

3.1.1 Internal Processes

a Preparation
- What are the methods that you use to anticipate and prepare for potential disruptions?

b Response
- What are the first steps taken after the impact of a disruption?
- What are the key roles or methods you execute during recovery operations?
- Do you inform your partners or other inner organisations of current or projected disruption?
- Are your preparedness plans used during recovery?
- What are the current challenges?

3.1.2 Suppliers/Customers

a Are your suppliers/customers helping you to build disruption preparedness? If not, how should they do that?

b Are your suppliers/customers helping to respond to a disruption event? If not, how should they do that?

c Are your suppliers/customers providing you any insights into future events or trends? If not, how should they do that?

3.2 What kind of disruptions are typical in your operations? Can you rate different parts of the supply network in terms of vulnerability to disruptions? Are there any example(s) to share of a disruption event?

3.2.1 Before Disruption

a When and how was the disruption first identified?

b How did it actually begin? Did you have any warning?

c Who (in what roles) were the first persons to identify the problem? Who else was affected?

3.2.2 Severity of Impact of the Disruption

a What was the immediate impact of the disruption?

b Did any of your SC partners notice or face any negative impacts caused by the event?

3.2.3 During and After the Disruption

a What was the initial response to the disruption? Was this completely successful?

b Did any of your actions make the problem even worse?
c Was your primary concern the time length of the impaction or the severity of disruption?
d Can you quantify the negative results caused by the disruption (e.g. financial, lead times)?
e Once the disruption was resolved, were there any takeaways to improve the system for the future?
f Do you have a control room to locate disruptions? If yes, can you provide more information?