Satakunnan ammattikorkeakoulu
Satakunta University of Applied Sciences

NÁNDOR HAJDU

COVID-19 pandemic and managing supply chain risks: NVIDIA's graphics card shortage case analysis

DEGREE PROGRAMME IN LOGISTICS
2021

Author:
Hajdu, Nándor

Type of Publication:
Bachelor's thesis

Date:
June, 2021

Number of pages:
53

Language of publication:
English

Title of publication:
COVID-19 pandemic and managing supply chain risks: NVIDIA's graphics card shortage case analysis

Degree Programme
Logistics

Abstract

The aim of the thesis was to uncover the underlying factors of NVIDIA's graphics card shortage besides the COVID-19 pandemic effects. Moreover, proposing solution techniques and methods to the identified issues based on selected literature. In this way, it was expected to reach a comprehensive understanding of the shortage from a supply chain risk management perspective.

In a case study setting, archival and documentary research was conducted to gather relevant information on the subject, relying on data from secondary sources such as journal articles, organizational reports, magazine articles, etc. The gathered data was processed using the pattern matching method to identify risks and vulnerability drivers, and to propose applicable solutions from the literature.

As the result of data analysis, it was discovered that the pandemic acts as a triggering event, and exploited vulnerabilities in the supply chain risk design, which have become risks such as supply capacity issues, transportation difficulties and unforeseen demand spike.
Solutions to address these problems were developed by using common literature suggestions in the topics of Supply Chain Resilience and Agility. There is a consensus in the literature on utilization of backup suppliers and shortening supply chains to limit the exposure and to be able to substitute the disrupted supplier.

In view of the findings, it can be concluded that shortage is a complex situation that is not only caused by the COVID-19 pandemic, but vulnerability drivers in the supply chain design contributed to the manifestation of the risks as well.

Key words
Supply chains, risk management, vulnerability, COVID-19

CONTENTS

1 INTRODUCTION

The thesis will examine the effects of the COVID-19 pandemic on Nvidia Corporation's supply chain, particularly the supply of their latest product generation, the GeForce RTX 30 series graphic cards. The thesis will focus on supply chain risks in the aforementioned context, and it will propose management concepts in response to the pandemic generated risks. The intention of this thesis to create a better understanding of such event's effects in supply chains and uncover suitable methods to manage the impact. The COVID-19 pandemic has severely impacted global supply chains and contributed to the emergence of semiconductor chip shortage that has been affecting many industries.

Semiconductor material is used to create integrated circuits (or chips), that are able to behave as a transistor to execute logical computations. Semiconductor material has the electrical resistance halfway between a conductor and an insulator, and through the process of doping it is possible to achieve the electrically controlled switching function (to act as either conductor or insulator), which way they become the transistors (MOSFET) in modern computer chips. In other words, semiconductors are the basic building blocks of processor units, and their presence is critical in other electronic devices (Ho 2014; Website of Advanced Micro Devices 2021).

Nvidia Corporation's products, such as their graphic cards are based on semiconductor technology. The company has been struggling to provide sufficient supply to their partners, delivering to retailers, and the result is a worldwide shortage of their products.

The emphasis of thesis is on gathering information on the matter rather than providing a concrete plan for business recovery. Coping with the disruptions caused by pandemic must be planned meticulously, tailored to individual circumstances. In the absence of information on Nvidia's operation details, a general recommendation of a set of strategies that will be developed which might be of some use. The thesis will focus on facilitating the understanding of risks in the context of pandemic and describing ways to manage them as opposed to creating a risk management plan.

The principal product in thesis is the Nvidia GeForce RTX 30 series graphic cards, specifically the graphical processing unit (GPU). The difference can be found in specification regarding performance.

These graphic cards are typically a part of computing devices with purpose of rendering images, and the main fields of applications are video gaming, video editing and lately cryptocurrency mining which utilizes the GPU's power.
The scope of the thesis is limited to the Nvidia's supply chain of manufacturing these products and delivering to final customers.

2 MAIN OBJECTIVES AND METHODOLOGY

It is a unique opportunity to examine an external threat effects on a global supply chain, especially when effects arise on such a massive scale and period, as during the COVID-19 pandemic. The project examines the effect of the pandemic and its relation to supply chain risks, and overall underlying factors that lead to the shortage of this particular product. Furthermore, the project proposes management concepts that are designed to address these risks. By doing so, it is expected to reach a better contextual understanding of situation that can be utilized to manage the threats. The result should contribute to a richer theoretical perspective of supply chain risk management, when an external threat, similar to the pandemic occurs.

The objectives of the research are as follows:

- What vulnerabilities the pandemic exploited in the supply chain? – To explore the underlying factors besides the pandemic.
- What are the effective management techniques for managing the threats conceived by the pandemic? – To suggest concepts and techniques to interested individuals affected by the pandemic for business survival based on selected literature.

2.1 Research process

Case study is defined as the empirical examination of a phenomenon in its real-life context, while reviewing evidence from multiple sources. The purpose of a case study

is to understand the relationship between the subject of the case within the context. Utilizing case study strategy would enable an in-depth view into the phenomenon in its real-life context, resulting in broader descriptions and expansion of theory. The thesis follows the orthodox case study approach, where theory is established first, followed by the preparation for the conduct of the research undertaken and data are collected, analyzed, interpreted and reported (Saunders, Lewis & Thornhill 2019, 196-197).

The thesis applies qualitative research design, which aims to create an interpretation of a phenomenon by using different data collection techniques and analytical methods (Pathak, Jena & Kalra 2013, 192; Teherani et al. 2015, 669). Qualitative data are non-numeric information in nature and derived from variety of sources such as publications, interview transcripts, figures etc., and the collected data is analyzed to uncover underlying reasons and motivations (Pathak et al. 2013, 192). The emphasis is on examining the situation in order to interpret the relationships between variables.

Considering the research strategy, using archival and documentary research within a case study is the appropriate method, taking the available resources into account. Archival and documentary research is based on utilizing secondary data sources, materials that can be accessed online (Saunders, Lewis & Thornhill 2019, 195). Since the lack of access to NVIDIA's internal data, the necessary information needs to be gathered from secondary sources to formulate the results. Secondary data means that the material was collected for different purposes than research (Saunders, Lewis & Thornhill 2019, 816). However, they can be further analysed to gain different knowledge, interpretation or conclusion. Saunders, Lewis & Thornhill (2019, 351) summarizes the advantages and disadvantages of secondary sources, Table 1. contains the headlines of these.

Advantages	***Disadvantages***
Quick access to data with less resources invested	Collected for different purposes than the researcher's need

Longitudinal studies may be feasible	Access can be expensive
Can provide comparative and contextual data	No control over data quality
New insights and discoveries are achievable	Initial purpose can impact the perception of data validity and reliability
Can be accessed by others to verify	

Table 1. Advantages and disadvantages using secondary sources (Saunders, Lewis & Thornhill 2019, 351).

The main data sources include the subject company's material such as annual reports, website data, and press releases. Furthermore, market reports and analysis, news articles that report on the subject, information published by partners in the supply chain are also assessed. All the sources were evaluated to ensure overall suitability to the research.

2.2 Data analysis

The qualitative analysis method being applied in thesis is the pattern matching specifically, which is part of the broader category of Explanation Building and Testing (Saunders, Lewis & Thornhill 2019, 666). Using the pattern matching approach, the applicability of the conceptual framework will be tested as a means to interpret the findings. The conceptual framework is based on the previously established theoretical review, and it is supposed to provide explanations to the pattern in the analyzed data. The advantage of this method is that it enables the researcher to initiate with a clear framework to guide the research process. It is also a deductive method, since the pathway to results is linear, theoretical implications lead the evaluation of the results.

It is suggested that route from the predicted explanations to the research objectives and questions should be well-defined and clear enough to understand the connection. There are two factors that play major roles in establishing a clear linkage (Saunders, Lewis & Thornhill 2019, 668):

- Level of thoroughness in applying the existing theory to define the conceptual framework and theoretical propositions
- Suitability of the above for the data is being revealed

The framework that will be applied in the data analysis is a slightly modified version of the one that van Hoek (2020, 344) used in his research of post-covid-19 supply chain management practices, and applying the literatures suggestion of environmental risk being the triggering event. In addition, risk identification will be carried according to the work of Tang and Musa (2011, 27), who categorized risks into material flow risks (with subcategorizes of source, make, deliver, SC scope), information flow, and financial flow. The patterning matching method would enable the identification of supply chain risks according to sources, and appropriate management practices are selected with respect to source categories as presented in Figure 1.

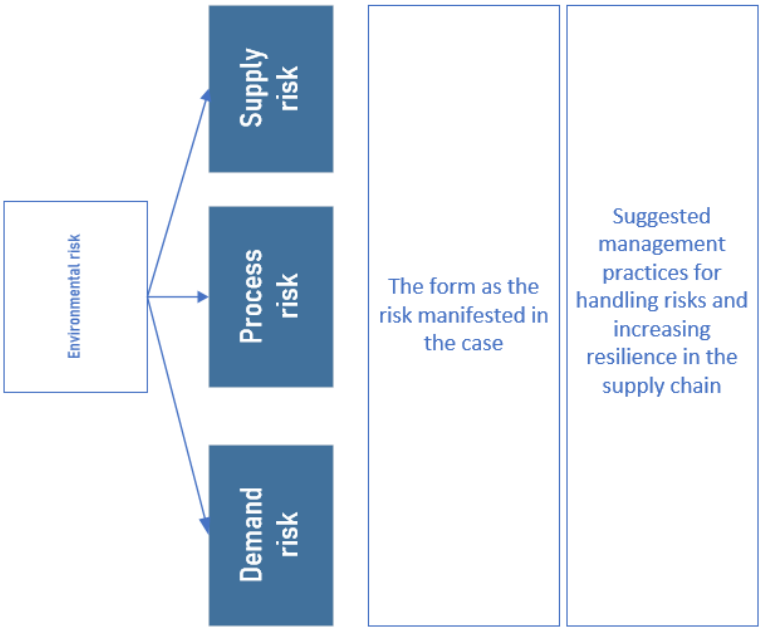


Figure 1. Conceptual framework applied in the research (van Hoek 2020, 344).

3 PRODUCT AND COMPANY PRESENTATION

NVIDIA Corporation (NVIDIA) is a Taiwanese – American global technology company that designs graphics processing units, mobile computing chips and develops different software applications to support the products. Their clients range from automotive players to governmental organizations. The number of employees is around 19,000 and headquartered in Santa Clara, California, United States (Website of Nvidia 2021). Major suppliers and customers are presented in Figure 2. (Ma 2021; Ma 2017).

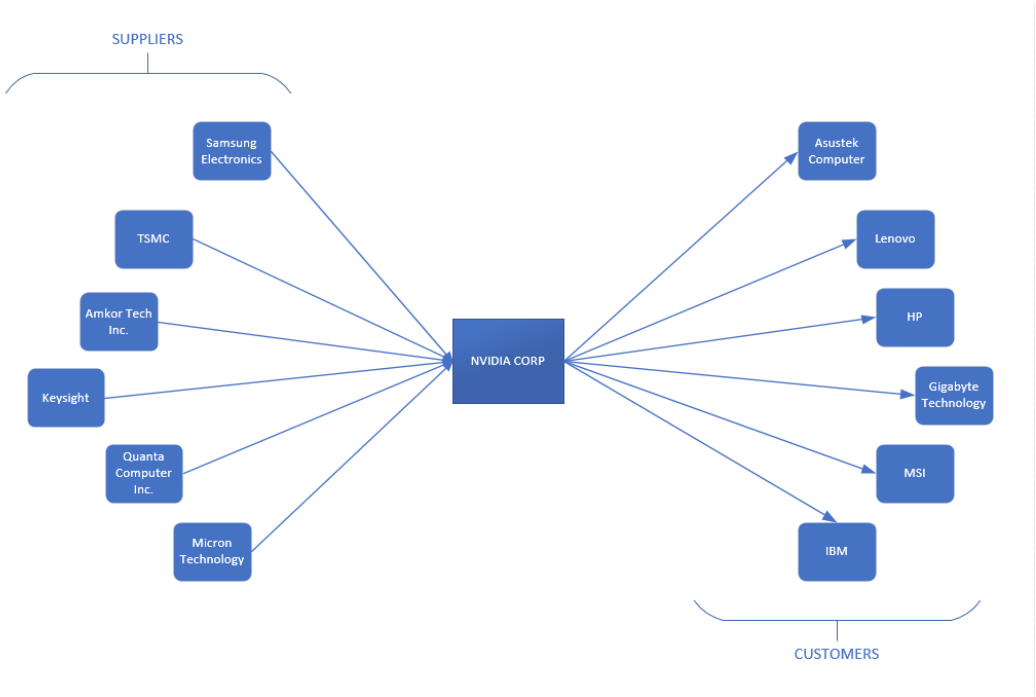


Figure 2. Major suppliers and customers of Nvidia (Ma 2021; Ma 2017)

The major brands target the following markets (Website of Marketline 2021):

- GeForce series GPUs for personal computer (PC) gaming
- Tegra processors (system on a chip units) for mobile gaming, gaming consoles, autonomous robots, vehicles
- Quadro for designers and professional visualization
- DGX and Tesla for AI and machine learning in big data research
- GRID for cloud-based computing services

Their latest financial figures (Website of Marketline 2021):

- Fiscal 2021 revenue was a record $16.68bn – 53% growth
- $7.76bn from gaming - 41% growth
- $6.7bn from data center – 124% growth
- $1.05 from professional visualization – 13% decline
- $536 million from automotive – 23% decline

One way to explain the growth is the work-from-home (WFH) trend. In the last year, people sought out different forms of indoor entertainment, hence the gaming gained a lot of attention. The new graphics promised a dramatic performance boost compared to previous product generation, and this performance boost will result in better visual presentation in the upcoming video games (Ma 2021).

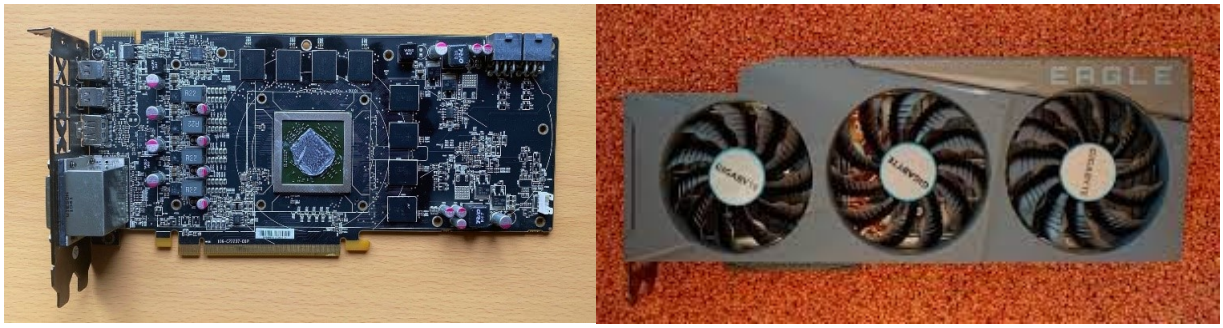
Data center growth is parallel to the growth of servers and cloud-computing services, which is also partially a side effect of the WFH. Table 2. contains an SWOT analysis of NVIDIA.

Strengths	Weaknesses
• Diversified operational presence helps to mitigate risks connected with region dependence • Strong focus on R&D fortifies technological leadership in visual computing • Strategic partnerships assists with providing better services	• Increase in accounts receivables hinders the company's financial status

Opportunities	Threats
• The company has introduced several new products recently • Positive outlook for semiconductors • Growing autonomous tech in automotive manufacturing industry • Growing data center market and high performance networking technology	• High competitive pressure that comes with the ever evolving technological industry • Cybersecurity risks in data center • Policies and regulations on technology have been gaining higher emphasis by authorities

Table 2. SWOT analysis of Nvidia (Website of Marketline 2021).

Nvidia's role in the graphics card development is designing the GPU. The actual manufacturing of GPUs is carried out by their partner, Samsung Electronics Co. LTD. The GPUs are forwarded to AIB partners (card manufacturers) such as ASUS, Gigabyte, MSI etc. that place the GPU in a printed circuit board and equip their custom designed cooling solutions, graphical connectors ports (HDMI, Displayport). They also make adjustment regarding the GPU's performance as they see fit. The naming of a graphics card that is available for purchase looks like e.g. Gigabyte GeForce RTX 3090. This particular product is shipped in the following package dimensions: 41x23.6x9.1 cm (LxWxH), and 2.075 kg.



Picture 1. Printed circuit board with ports on the left and the commercial product of RTX 3090 by Gigabyte (Website of Wikimedia Commons 2021; Evanson 2020)

Nvidia also make full-scale graphics cards, so called founder's edition or reference model. These products are usually intended for testers, clients and partners to test capabilities of the GPUs. It is not meant for consumers and usually not available at retailers.

Picture 2. The founder's edition of RTX 3090 (Website of Wikimedia Commons 2021)

As previously mentioned, the main market for graphics card is the video gaming market where real time 3D image rendering is necessary. There are application opportunities for professional markets such as video editing (exporting) and 3D visualization (Solidworks, Autocad, VFX etc.). AI research, Deep Learning and supercomputing are based on GPU's power as well. In the recent years, cryptocurrency mining participants has been dominating the GPUs sales, since the mining efficiency is greatly increased by the GPU's power.

4 UNDERSTANDING SUPPLY CHAIN RISK MANAGEMENT

The earthquake and tsunami that occurred in Japan in 2011, generated huge losses all along the supply chain of automakers and electronics manufacturers. As being one of the major manufacturing hubs in the world, including companies that provide crucial raw materials for semiconductor chips and supplying dynamic random access memory and flash memory in logic controllers, liquid crystal parts. After the disruptive event,

the prices of such components increased by 20% in the global market, affecting global automakers and electronic manufactures that are dependent on the Japanese suppliers (Park, Hong & Roh 2013, 76).

Supply chain disruptions caused by an external event are difficult to anticipate due to supply chain's increasing complexity and interconnections, but they pose a severe threat that could damage businesses harshly. Certain practices in the industries such as outsourcing, just-in-time and shorter product life cycles have contributed to the increased exposure to supply chain risks (Heckmann, Comes & Nickel 2015, 1).
In order to understand the COVID-19 impact on NVIDIA's supply chain, specific concepts and terms need to be clarified. In the following section, a theoretical overview is presented in the topic of supply chain risk management (SCRM).

4.1 Necessary concepts

Because of the complexity of SCRM, it is reasonable to break down the concept, starting with the definition of risk. Since the implication of risk is broad, the organizational context needs to be added in order to be relevant to the case. Hopkin (2017, 16) suggests that risk should be considered as an event that is able to affect the efficiency of the core process of an organization. According to Khan & Zsidisin (2011, 2) risk comprises the possibility of both negative and positive outcome. However, organizations tend to navigate towards the negative connotation of risk in their business operation considerations. This also resulted in that cases with negative emphasis have received more attention from the research community, and theoretical knowledge is richer in regard to this particular aspect.

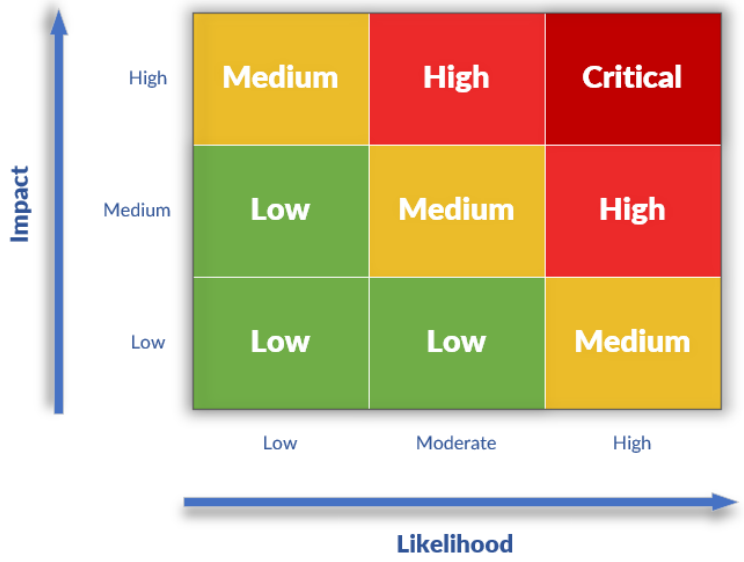


Figure 3. Risk matrix is a common tool in risk assessment (Website of Goverment of Canada, 2013)

When it comes to risk management, the approach can vary based on the context of application. A general definition is proposed by Hopkin (2017, 46), which follows as the set of activities that focus on acquiring the positive outcome and reduce the likelihood of the occurrence of the undesirable. Risk management is considered being concerned with uncertainty, hazards and opportunities, and it is constantly evolving. Numerous organizations employ professionals in several branches such as tax, procurement, finance, human resources to assess the risk in their respective operations and develop assurance against disruptions (Hopkin 2017, 49). Figure 3. exhibits a simple risk matrix, that is used to assess the likelihood and impact of a given risk that might affect the company's operation processes.

Considering risk and risk management from a supply chain perspective, defining supply chain is necessary in the first place. It can be defined as "A network of connected and interdependent organisations mutually and cooperatively working together to control, manage and improve the flow of materials and information from suppliers to end users" (Christopher 2016, 3). It involves a company, a supplier and customer, and between these entities there are upstream and downstream activities dealing with products, services, finances and information (Jüttner 2005, 121).

Supply chain management (SCM) focuses on planning, monitoring and controlling the supply chain network, and facilitates different types of flows among the producers to the final customer while maintaining high efficiency and customer satisfaction (Heckmann, Comes & Nickel 2015,123). Common activities within a supply chain showed in Figure 4.

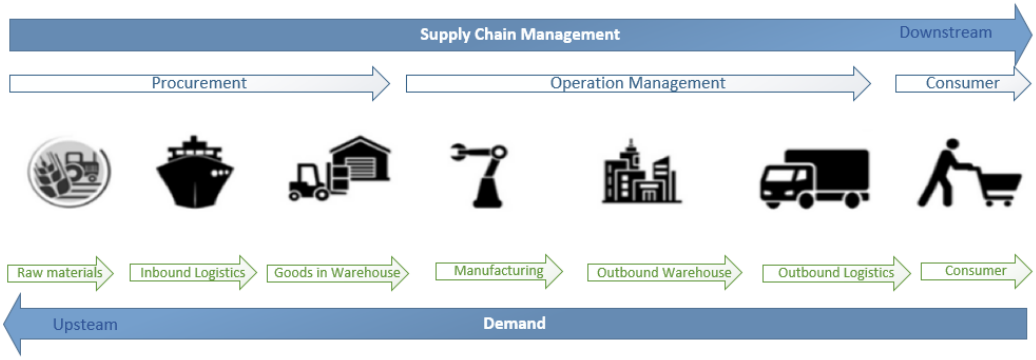


Figure 4. Simplified presentation of a supply chain (Website of Chartered Institute of Procurement and Supply, 2020)

4.2 Supply chain risk identification

Interpreting risk in this context, the definition should be revised according to supply chain characteristics. Heckmann, Comes & Nickel (2015) identified the core characteristics of supply chain risk based on reviewing existing literature in their development of their proposed definition:

- Objective-driven risk: concerns the objective of supply chain management, in general these are efficiency and effectiveness, which refer to executing supply chain activities with minimal waste and cost. On the other hand, inefficiency leads to in a form of loss for the organization.
- Risk exposition: involves the occurrence of a triggering event, affected supply chain characteristics and time-based characteristics (Heckmann, Comes & Nickel 2015, 123-126).
    - Disruptive triggers: It is the combination of probability and event. Probability distribution based on available information (certainty, risk and uncertainty) govern the input and output of decision making. Triggering

events are perceived and assessed based on their severity of impact on supply chain goals and frequency of occurrence. Uncertain events indicate lack of probability information, but they pose a high impact on the supply chain.

  - Affected supply chain: On one hand, it refers to vulnerability of supply chain, which is the extent to a supply chain exposed to a risk. On the other hand, there is supply chain resilience, that describes the ability to overcome vulnerabilities.
  - Time-based characteristics: it comprises time related aspect of management activities such as detection and designing solution to disruptive triggers, length of recovery etc.
- Risk attitude: the subjective perception of the importance of risk. Risk-averse or risk-neutral are present in the literature.

Therefore, applying the characteristics in the definition, the following is the result: "the supply chain risk is the potential loss for a supply chain in terms of its target values of efficiency and effectiveness evoked by uncertain developments of supply chain characteristics whose changes were caused by the occurrence of triggering-events"(Heckmann, Comes & Nickel 2015, 130).
In simple terms, risks manifest in the form of disruption of flows in supply chains, where flows are interrelated and they can be information, product, raw material, capital. The main distinguish factor is the plural implication by the supply chain, the disruption can affect multiple nodes in the chain (Jüttner 2005, 122).

Within supply chain risks, a categorization can be established according to sources. Supply chain risk source is defined as any variables that are unpredictable and conceives disruptions. Jüttner (2005, 122) describes environmental, supply, demand risk sources, and considers process and control as either amplifier or absorber with respect to organizational resilience. It is suggested that these risks overlap (Figure 5.) , and environmental risk can induce supply and/or demand risk, and considered as a disruptive or triggering event (Jüttner 2005, 122; Heckmann, Comes & Nickel 2015, 130).

- Environmental risk : external uncertainties emerging from the supply chain in the form of disruption caused by political, natural or social uncertainties (Jüttner 2005, 122).

- Supply risk: risk events on the supply side that contain supplier defaults or different unanticipated changes. In addition, overall uncertainty with supplier activities and relationships (Jüttner 2005, 122). Supply risk can include supplier failure, supply commitment, outsourcing, supply cost (Sodhi & Tang 2012, 23).
- Process/operational/control: there is no concrete definition for this category, but it refers to resilience of processes within the supply chain, how vulnerable operational processes such as supply chain bottlenecks or IT system stability etc. Sodhi & Tang (2012, 24) describe it as internal supply chain risks that concern design, manufacturing and distribution.
- Demand risk: uncertainty surrounding product demand in terms of volume and product mix (Sodhi & Tang 2012, 26). It can occur by inbound disruptions or by seasonality, new product adoptions, short product life cycles etc. (Jüttner 2005, 122).

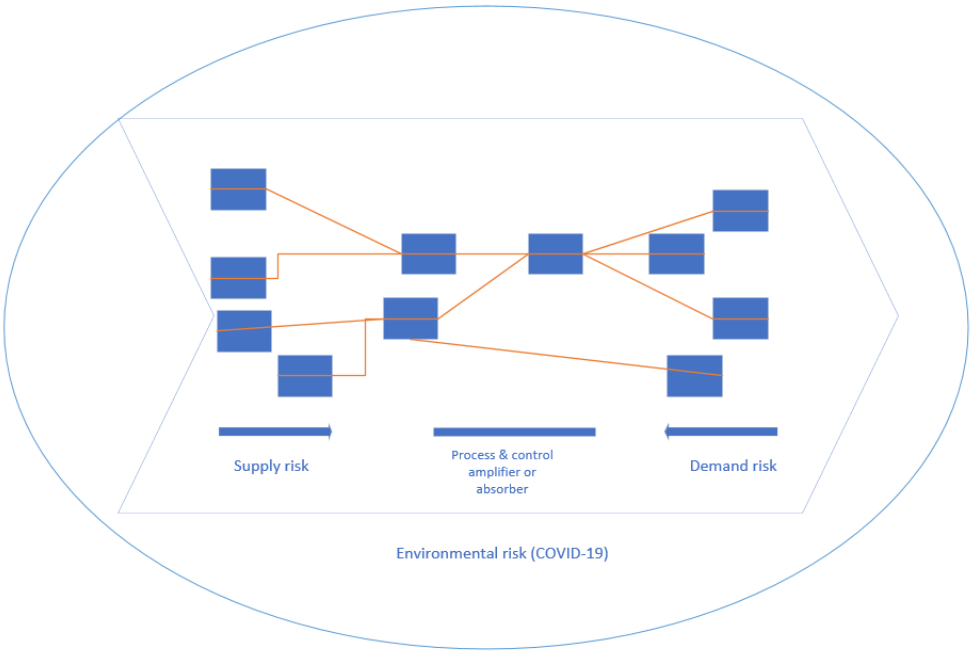


Figure 5. Overlapping relationships between risks (Jüttner 2005, 123)

Christopher and Peck (2004, 6) considered external and internal supply chain risks. They differentiate between internal company and cross-company-based supply chain risks within internal risks. Internal company risks refer to problems that lie within organizational boundaries e.g. machine breakdown, IT system malfunction. Cross-company based supply chain risks are separated to demand and purchasing risks. External

supply chain risks are circumstantial, environmental risk sources that are barely controllable and can disturb supply chain activities directly or indirectly.

Tang and Musa (2011, 27) emphasize the importance of integrating activities, as they should be merged with main supply chain processes, and not functioning on their own. For example, the risk concern of stable flow of raw material should start with careful supplier selection. According to their literature survey, they identified three major risk issues and broke down further each to individual flows (Table 3.):

- Material flow: refers to the physical movement between the nodes within the supply chain.
    - Source: acquiring goods and services.
    - Make: it centers around the execution of production and product development, and operational support
    - Deliver: concerns the forecasting ability to meet customer demand and coping with technological change
    - Supply chain scope: includes interconnected activities that are present in the previous categories
- Financial flow: risk involves the mishandled investments and payment unfulfillment.
- Information flow: the authors refer to it as the bonding element between financial and material flow.

Material flow	Financial flow	Information flow
Source ❖ Single sourcing risk ❖ Sourcing flexibility risk ❖ Supply product monitoring/quality ❖ Supply capacity ❖ Supplier selection	❖ Exchange rate risk ❖ Price and cost risk ❖ Financial strength of supply chain partners ❖ Financial handling and practice	❖ Intellectual property ❖ Information accuracy ❖ Information system security and disruption
Make ❖ Product and process design ❖ Production capacity risk ❖ Operational disruption		
Deliver ❖ Demand volatility/Seasonality ❖ Balance of unmet demand and excess inventory		
Supply chain scope ❖ Logistics ❖ Price volatility of commodity and alternative energy ❖ Environment degradation and awareness ❖ Political risk ❖ Cultural and ethics ❖ Supply chain partners relationship		

Table 3. Main flows and risks elements (Tang and Musa 2011,28-30).

Thun and Hoenig (2011, 245) presented a set of supply chain risks in a probability-impact matrix with regard to internal and external risk categorization. In their empirical analysis of automotive supply chains, they found that internal supply chain risks have a higher chance to occur compared to external risks. In addition, external supply chain risks do not necessarily have higher impact than internal risks. Furthermore, one of their hypotheses was that complexity and efficiency should be regarded as key drivers for risks in the supply chain context. As the result of the analysis, they also identified drivers that would increase the vulnerability of supply chains to disruption (Figure 6.) such as outsourcing, globalization, central distribution, reduction of suppliers etc.

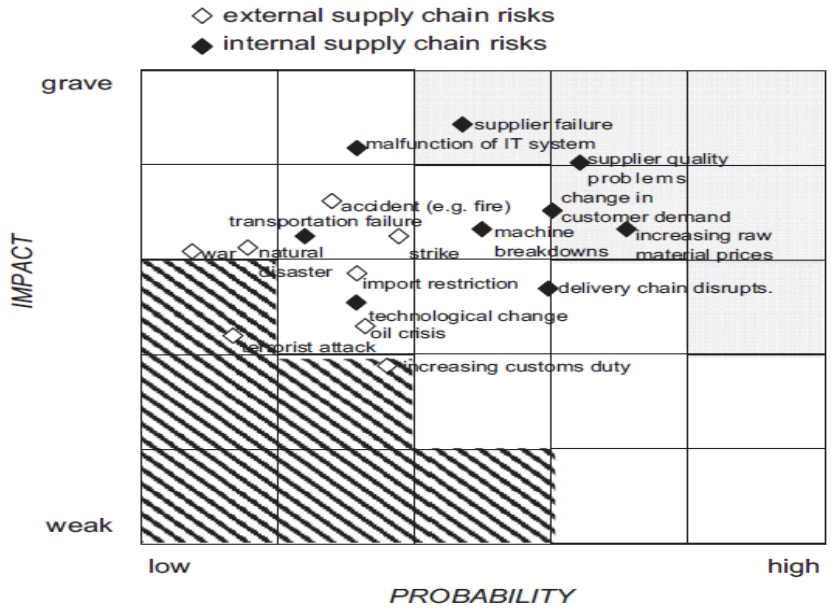


Figure 6. Supply chain risks with impacts and probability (Thun and Hoenig (2011, 246).

4.3 Defining SCRM

The process of performing SCRM includes risk identification, risk assessment, risk treatment and risk monitoring in the form implementing SCRM strategies. Furthermore, external coordination and cooperation between supply chain participiants are also necessary, and these participants are expected to implement the strategies internally as well (Fan & Stevenson 2018, 6).

The objectives of SCRM can be comprised of two main activities (Fan & Stevenson 2018, 7):

- Cash-flow management in order to save cost and maintain profitability
- Securing business continuity and reducing vulnerability

It is indicated that efficient SCRM can lead to better market position, in case it is more successful than competition (e.g. Lenovo's acquisition of Motorola Mobility). Thus, potentially longer-term growth is one of the benefits of well-executed SCRM (Fan & Stevenson 2018, 7).

Fan & Stevenson (2018) developed a comprehensive definition of SCRM, which is considered to be internally consistent, that comprises the relationship among risk management and SCM, and the versatile nature of application. So the definition is "the identification, assessment, treatment, and monitoring of supply chain risks, with the aid of the internal implementation of tools, techniques and strategies and of external coordination and collaboration with supply chain members to reduce vulnerability and ensure continuity coupled with profitability, leading to competitive advantage"(Fan & Stevenson 2018, 7).

The definition is connected to a conceptual framework, the objective-process-outcome based SCRM (Figure 7.), that is designed to address the supply chain risk, ensure a positive outcome, and generate a competitive advantage for the supply chain partners. It is also intended to clarify objectives of SCRM, choosing appropriate strategies meanwhile examining the external and internal pathways' impact on the process and inspecting the results utilizing a holistic perspective (Fan & Stevenson 2018, 7-8).

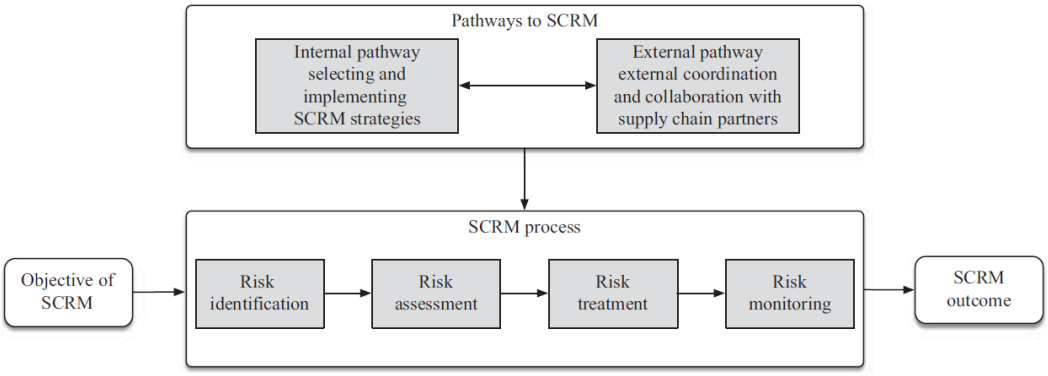


Figure 7. Proposed SCRM conceptual framework by Fan & Stevenson (2018, 7).

4.4 COVID-19 pandemic – Supply chain effects in general

According to the OECD's Economic Outlook (Website of OECD, 2020), the COVID-19 pandemic has caused one of the most severe recession in nearly a century, affecting people's health, jobs and well-being in a damaging way. 94% of the Fortune 1000 companies were experiencing some form of disruption in their supply chains (Chowdhury et al. 2021, 2). The merchandise trade was down 7% in 2020, and commercial services exports fell 20% (Website of World Trade Organization, 2021).

The uniqueness of this pandemic is that it has impacted all the supply chain members (nodes) and their ties to each other simultaneously. Therefore, the flow of goods and services in supply chains has been interrupted significantly by the pandemic. One of the bases of disruptions is the containment measures that governments were forced to deploy in order to slow the spread of the virus and stop the increasing death toll (Chowdhury et al. 2021, 2).

However, these measures also resulted closures of businesses and services in several sectors and major economic hardship begun emerging. Figure 8. presents the world merchandise trade volume in the indicated time interval, and projects two scenarios based on success of vaccination efforts and economic response (rate of growth, trade and debt).

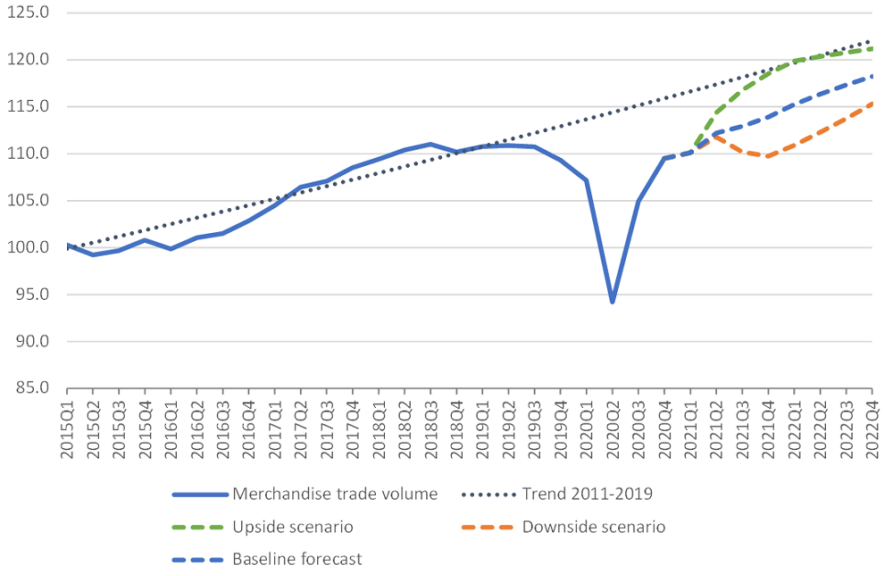


Figure 8. Two scenarios of outcome (Website of World Trade Organization, 2021).

The main challenges that supply chains have to overcome in their operations originate from these occurrences are shown in Table 4.

Border closures Lockdown in the supply market Disruption in international trade and vehicle movements Labor shortage Physical distancing in facilities	Supply unavailability Transportation difficulties Production challenges	Demand fluctuation from panic buying and stockpiling behavior

Table 4. Factors affecting supply chain operations during COVID-19 (Chowdhury et al. 2021, 2)

Supply challenges emerge to a certain extent from the full or partial lockdowns around world, the restriction of movement makes it difficult to deliver products to customers in agreed time of arrival. According to Guan et al. (2020, 581), prolonged labour and transportation constraints in Germany and in those countries where the suppliers are located could result in significant drop (approx. 28%) in the German automotive sector during the period of the lockdown. Furthermore, the PwC (2020) reports that global supply chains in the manufacturing sector are likely to be impacted on Tier 2 and Tier 3 level, making it difficult to deliver components and raw material to the manufacturing plants.

Besides the uncertainty in supply, production side of supply chains faces workforce capacity constraints. Labour shortage and temporary plant closures due to infections significantly disrupted the material flow, suppliers working at reduced capacity lead to longer final product lead times (Ivanov & Das 2020, 91). Reduced capacity led to placing certain machinery, facilities and different capital assets in idle, which can be considered as waste of resources (Dente & Hashimoto 2020, 2).

When it comes to transportation and logistics management, the pandemic has impacted the ability to deliver and obtain products on time due to shortages and logistics bottlenecks (Kumar et al. 2020, 4). The COVID-19 caused the diversion or disruption of trades routes. Even though port operation is an essential service, the throughput significantly declined due to labour shortages and weak material flow. Consumers' increasing preference of online shopping challenges the capacity of supply chains to ship products on time. The phenomenon prompted retailers to reduce the number of stores and establish distribution centers, that solely serves the online orders (Mollenkopf, Ozanne & Stolze 2020, 6).

As aforementioned, the consumers' purchasing behavior massively impacted the demand side of supply chains. Essential products such as food, medicine, sanitary have been under huge demand and some cases it led to temporary product shortages (Chowdhury et al. 2021, 10). Panic buying of storable goods commonly occur during natural disasters and crises situations (Keane & Neal 2021). According to Chua et al (2021,18), the panic buying is affected perceived scarcity and anticipated regret. Consumers want to get hold on the product which is in limited supply, in order to avoid regret of not purchasing it while they still can. Demand fluctuation creates places supply chains in uncertainty, making forecasting activities extremely complicated and causing hardships decision-making related to price of the product.

Last but not least, supply chain relationship management has been also affected, specifically the social interactions. The lack of interaction resulted in information incompleteness and inaccuracy, and supplier engagement has been also less effective which might reflect on collaborative efforts (van Hoek 2020). Gupta et al (2021) studied the supplier and retailer relationship in regards to competitive pricing under supply disruption, and they found the disruptive situation increases the opportunistic behavior of the non-disruptive supplier e.g. strengthened negation position, setting prices, higher order quantity, promotion activities etc.

In the next section, supply chain risks related to the pandemic and vulnerability drivers will be discussed as they manifested in the case.

5 RISKS IN NVIDIA'S SUPPLY CHAIN

5.1 Recognizable vulnerability drivers in the case

There are certain supply chain characteristics that can influence vulnerability, the latter is regarded as the exposure to an impactful disturbance. These characteristics sometimes referred to as drivers, that result in vulnerabilities of supply chain (Wagner & Neshat 2010, 122). Examining NVIDIA's supply chain, there are identifiable drivers present in their case. The list is established based on the work of Thun & Hoenig (2011, 246), Wagner & Bode (2006, 305) and Wagner & Neshat (2010, 126):

- Outsourcing
- Supplier dependence
- Lean inventory
- Supplier concentration
- Global sourcing
- Supply chain complexity

Supplier dependence is one of the drivers because of NVIDIA's reliance on SEC's foundry. The availability of their products is affected by foundry's production efficiency and capacity. Lack of in-house production comes with lower-level control over the production process, resulting high dependence on the vendor's manufacturing capabilities. There is only one alternative manufacturer, Taiwan Semiconductor Manufacturing Co. (TMSC) that is capable to deliver the necessary process node (8nm/7nm). However, TMSC is already at their maximum capacity, currently only producing one type of GPU to NVIDIA, A100 GPU, which is intended to industrial partners (AI research and cloud computing) (Website of NVIDIA, 2021). In this case, NVIDIA is exposed to supply-side disturbance with no option to substitute.

Supplier concentration and global sourcing can be considered drivers as well, due to fact that semiconductor manufacturing is highly specialized and sophisticated industry with well-established suppliers. Examining manufacturing locations, it can be concluded that most of the are based in East Asia, and with some exceptions in the USA.

Graphics card distributors are scattered around the globe but ASUS, MSI wholesalers centralized in mainland China (Shenzhen, Wuhan, Guangzho) (Website of Alibaba, 2021; Website of Global Sources,2021). There are complicating factors that need to be considered in transportation, for example extensive lead-time because of long routes, border crossing (taxes, duties) and material handling on the top of an external disturbance (Wagner & Bode 2006. 306).

Supply chain complexity is high in NVIDIA's case, working with several subcontractors, suppliers. Therefore, coordinating supply chain processes are particularly difficult. NVIDIA uses fabless manufacturing strategy, that means it is only concerned with design and software support. On the other hand, manufacturing, testing, packaging and distribution belong to other companies, in other words high level of outsourcing is observable, which they explain with focusing on solely on core competence and staying profitable (United States Security and Exchange Commission, 2018). In addition, NVIDIA's products are distributed worldwide, which further increases the complexity and necessity of outsourcing such as after-sale and service support. Hence, high supply chain visibility can be challenging to achieve when there are so many nodes to follow.

Lean production is applied at SEC's manufacturing (Website of Samsung, 2021; Suh & Kim 2009, 107), and the concept has gone under re-evaluation since the pandemic emerged by professionals and researchers (Bryce et al. 2020, 883; Fonseca & Azevedo 2020, 429; Garnett, Doherty & Heron 2020, 315). The argument is that approaches such as just-in-time logistics and lean inventory tend to overlook the systematic risks posed by supply chain disruptions (Garnett et al. 2020, 315). However, there is a lack of evidence that supports the claim that lean production is a direct contributor to shortage situations. A counter argument is that lean production does not imply zero-stock policy, but it rather works with minimized inventory, and poor implementation what causes the problem e.g focusing on lowering cost, lack of supply chain visibility and inefficient coordination (Netland 2021). Furthermore, lean thinking advocates for continuous improvement, which indicates that rethinking and adjusting supply chains to the circumstances should be considered by the management.

5.2 Transportation difficulties

Van Hoek (2020, 346) discusses several experienced supply risks by supply chain executives that are related to delay of shipping pipelines, long lead times due to plant closures, and overall failure of logistics networks. These do not only affect NVIDIA and its partners, but global supply chains as well that use maritime transportation.

The most significant form of supply disruption is the transportation difficulties of goods and services. The surge in freight rates and shortage of shipping containers affected several industry sectors (Website of UNCTAD 2021; Attinasi, Bobasu & Gerinovics 2021). The disruption in global trade and sharp bounce back, companies rushed to reduce the built-up inventories and order backlog that were created in the first half of the year (Figure 9.). Furthermore, there has been an unprecedented number of empty containers, due to the lack of warehouse workers and truckers, ports and stevedore companies are unable to meet the demand.

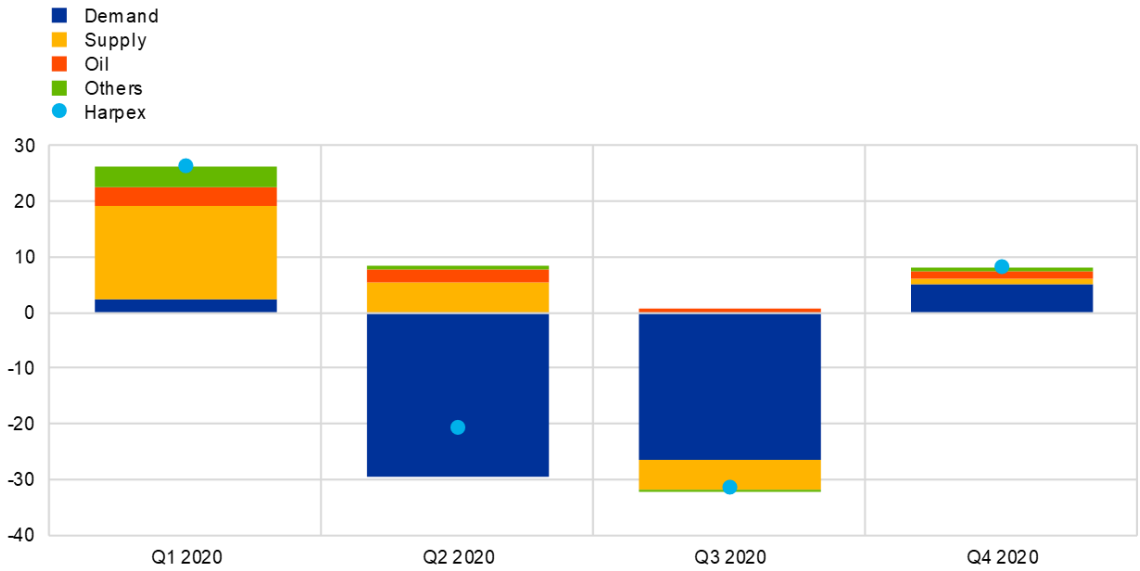


Figure 9. Fluctuation of demand, supply and costs in shipping in 2020 (Attinasi et al. 2021).

The GPU manufacturing is carried out in Hwaseong, South Korea. The finished products are expected to shipped to AIB partners, where the graphics cards are actually assembled for commercial use. Most of these facilities are located in mainland china, one Taiwan and USA (Website of ASUS; GIGABYTE; MSI; Palit; ZOTAC; 2021).

From Hwaseong, the transportation mode is most likely either air transport or maritime shipping, probably the latter considering cost and volume. There is a logistics center located in Hong Kong (Website of Bloomberg, 2021), however it is unclear whether NVIDIA use it for distribution to AIB partner plants or wholesale of finished products (data center, automotive etc.).

Figure 10. Shipping from South Korean to the AIB Partner plants.

If the logistics center is utilized in the flow to the AIB partners plants, the GPUs should be arrived in Port of Hong Kong (Figure 10.). Since the emergence of the pandemic, the movement of goods and service between mainland China has been restricted. The port struggled with low worker capacity throughout 2020, limiting the stevedoring services, due to high number of infection cases (Cheng et al. 2020; Schwerdtfeger 2020).

In the second scenario point-to-point transportation network seem to be applied (Esmizadeh & Mellat Parast 2021), which means the GPUs go straight to AIB partners' facilities. To mainland China, the products would enter through Port of Shanghai and Port of Shenzhen. Both of these ports experienced restrictions, workers were quarantined etc. resulting in limited throughput (Wallis 2021). There is no public report on disturbance regarding Port of Taipei.

Considering the manufacturing plant in New Jersey, the GPUs can be transported through Port of New York and New Jersey, and Port of Los Angeles. The route from

Los Angeles is faster, the cargo would be transferred onto truck in the rest of journey to New Jersey (NJ), whilst the shipping route to NJ would be significantly longer. About truck transport efficiency during COVID-19, The American Transportation Research Institute (2020) reported that long-haul truck movements with international containers decreased by apprx. 10% in the first half of 2020, due to the road freight carrier prioritized towards local transportation of essential goods and lower volume of incoming material China. The road freight industry generally benefited from the situation, because of the low oil prices and less-congestions on the road. However, loading and unloading time are perceived to be increased by drivers.

Shipping industry had been expected to recover in the early 2021, because of the Chinese New Year holidays production facilities usually suspend their operation. However, Chinese factories pressured employees to keep working during the holidays to meet the global demand (Liu & Hale 2021). Even though NVIDIA itself does not have any manufacturing going on in mainland China, their supply chain does operate several facilities all over the country, manufacturing of PCB, connectors, VRAM etc.

Surge in shipping costs is commonly transferred to consumers, which reflect on retail prices. It is reported that EVGA, MSI and Zotac partners have increased their prices of their graphic cards, assuming partly due to supply constraints (Hollister 2021; Casas 2021a). In order to return to manageable prices, the capacity supply of shipping has to meet the demand and overcome bottlenecks (Attinasi, Bobasu & Gerinovics 2021) .

This section corresponds to the logistics risk element in material flow (Tang & Musa 2011, 28). It does not affect only one node, but the whole supply chain experiences the impact. On the other hand, van Hoek (2005) mention transportation difficulties among supply risks, because the movement of goods and services can be associated with suppliers. However, el Abdellaoui and Youssef (2017) discuss transportation risks of upstream and downstream of the supply chain, but only as micro risk that arise from minor disturbances and impacts logistics performance i.e. within internal risk.

5.3 Capacity bottleneck

The process side risk that NVIDIA is facing is the insufficient capacity from Samsung Electronics Co. Ltd (SEC) (Hagedoorn 2020). The demand was not anticipated correctly which also led to shortage of wafer (raw material) supply at SEC's foundry. There is also struggle with availability of components and different substrates. Furthermore, NVIDIA was not satisfied with the SEC's low process yield rate, and considered it as one of the main reasons of shortage situation (Hwang 2020). Moreover, SEC's foundry already operated at maximum capacity (Figure 11.)
Therefore, expanding the production capacity at SEC's production facilities is not possible in the current circumstances.

(Hours)

Division	Item	2020		Utilization rate
		Potential production time	Actual production time	
DS	Memory	73,248	73,248	100.0%
	Display Panel	70,272	70,272	100.0%

Figure 11. The DS division includes foundry operations (Website of Samsung, 2020).

Sodhi & Tang (2012, 38) considers both uncertain yield and capacity as part of process risks, because it indicates that plant is unable to provide the desired output to its demand. According to the categorization of Tang and Musa (2011), production capacity and sourcing related risks are recognizable in this section. Furthermore, the low-yield rate indicates product and process design risk, which can be related to supplier selection risk, as it is not able to deliver the desired amount of acceptable product on the line.

SEC's foundry is located in Hwaseong, South Korea (Website of Samsung, 2020). The pandemic did not affect significantly the throughput of the foundry in 2020. Only one of the many domestic plants was forced to shut down for a few days, but no related operation takes place to the GPU production. The major problem SEC faces is the access to supply, since tier 2 and tier 3 are mostly located in Japan, USA and China (Website of Samsung 2021). 90% of the raw wafers are provided by FST, GlobalWafers, SEH, Siltronic, SUMCO, and SEC has to compete with Taiwan Semiconductor

Company (TSMC) to reach sufficient supply (Website of TSMC, 2020). TSMC is currently the largest semiconductor manufacturer with higher investment in the foundry sector, and possess larger production capacity than SEC (Eun-jin 2021a). Hence, increasing procurement of raw material is also a troublesome effort.

The shortage also caused some disturbance in supplier relationships. Asus considered the shortage as the result of lower yields upstream from NVIDIA compared to previous years (Coberly 2021; Casas 2021). On the other side, as mentioned before NVIDIA called out SEC's inability to ensure uninterrupted silicon wafer supply and lower yield rate (Hagedoorn 2020). MSI partially reasoned the price increasing due to the short supply (Casas 2021a). The tension hinders the effectiveness of supply chain relationship management, and partners expect solutions to the problem from NVIDIA, which is constrained by the SEC's capacity and unable to substitute the production of their GPU.

5.4 Overwhelming demand

The demand spike is considered being the major factor by the side of NVIDIA (Hagedoorn 2020). There are two sub-categories of demand risks that are present in the case: forecasting, change in technology and in consumer preference (Sodhi & Tang 2012; Tang & Musa 2011). Forecast risk refers to the misalignment of a company's forecast and actual demand experienced. Lockdowns and movement restrictions increased people's interest in indoor entertainment, which from the gaming industry benefited heavily (Figure 12. shows the US market). Indeed, the revenue from gaming services and software grew approx. 22% in 2020, approx. 20% increase in PC gaming sales, where NVIDIA's graphics cards are utilized (Xue 2021). The new products promise significant performance boost compared to the previous versions and includes some of the latest visual enhancing technology developed by NVIDIA (ray tracing), hence the high interest by individuals in the gaming sphere.

Cloud service market segment is also benefited from the restrictions, which is the foundation for videoconferencing, online shopping, video gaming and streaming. Cloud

computation takes places in large centralized data centers, where NVIDIA made their largest Year-on-Year (YoY) revenue growth (Waters 2021). Data centers use differently built GPUs, but similar resources used in the production and it also occupies capacity at SEC's foundry, reducing the RTX 30 series output.

The effects of shortage are the most apparent at retailers. Some decided to apply different techniques to control the demand such as bundling with other components (motherboard, cpu) or organizing raffles to distribute purchase rights (Casas 2021b). But since the supply is limited, prolonged stockouts are unavoidable. Finnish local retailer Jimm's (Website of Jimm's, 2021), can only receive the graphics cards in small batches, assuming they experience challenges to secure supply. The small quantity disappears quickly, which leads to frequent orders, increasing transportation cost significantly. Further motivation for charging much higher prices compared to the MSRP. The recently released RTX 3070TI and RTX 3080TI models got sold out on launch day at several US retailers (Widder 2021). As an example, one of the biggest consumer electronics retailers in the USA, Best Buy received 5000 pieces of RTX 3080TI for launch day, which were distributed all over country. Best Buy limited the sale to only in-store, but the supply still came short whilst the demand was overwhelming e.g. 64 pieces available in the whole city of Los Angeles, while approx. 200 consumers lined up for store opening to purchase a graphics card (Kan 2021b).

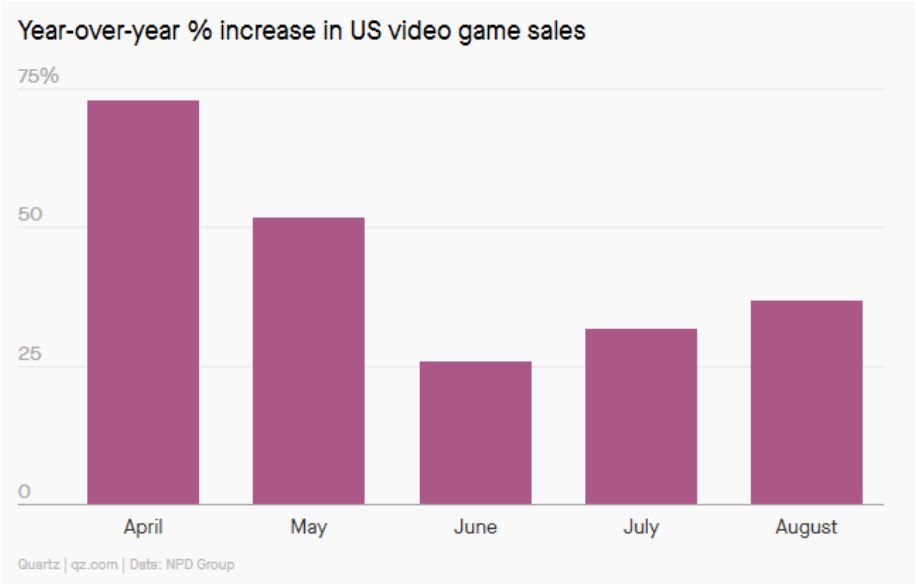


Figure 12. Video game sales in the US market in 2020 compared to the previous year (Epstein 2020).

Another unanticipated phenomenon is the cryptocurrency mining which also massively impacted the availability of NVIDIA's graphics card (Kim, T. 2021). In the recent years, crypto miners have actively invested in high-end GPUs that are faster more efficient at completing the mining process. In fact, crypto mining has been blamed by the gaming community for the shortage, and NVIDIA decided to limit mining capabilities in their RTX 3060 card, announced it would limit RTX 3080 and 3070 in mining as well (Warren 2021a). Furthermore, they released the NVIDIA CMP HX product group in the first quarter of 2020, which is specifically designed for efficient mining (Website of NVIDIA, 2020). The intention with the mining card is presumably to capitalize on the coin market expansion, and shift the demand from the RTX 30 series cards that are intended for gamers.

In summary, the combination of these factors resulted in the worldwide RTX 30 series graphic cards shortage. The retail prices of these graphics cards are often double or triple the manufacturer recommended sale price (MRSP), even from second hand sources (Figure 13.).

COVID-19 pandemic has had the largest the impact on the demand risks, and restrictions related to performing production and transportation (WFH, limiting movement, distancing etc.) prevented supply chain nodes to respond to the shortage.

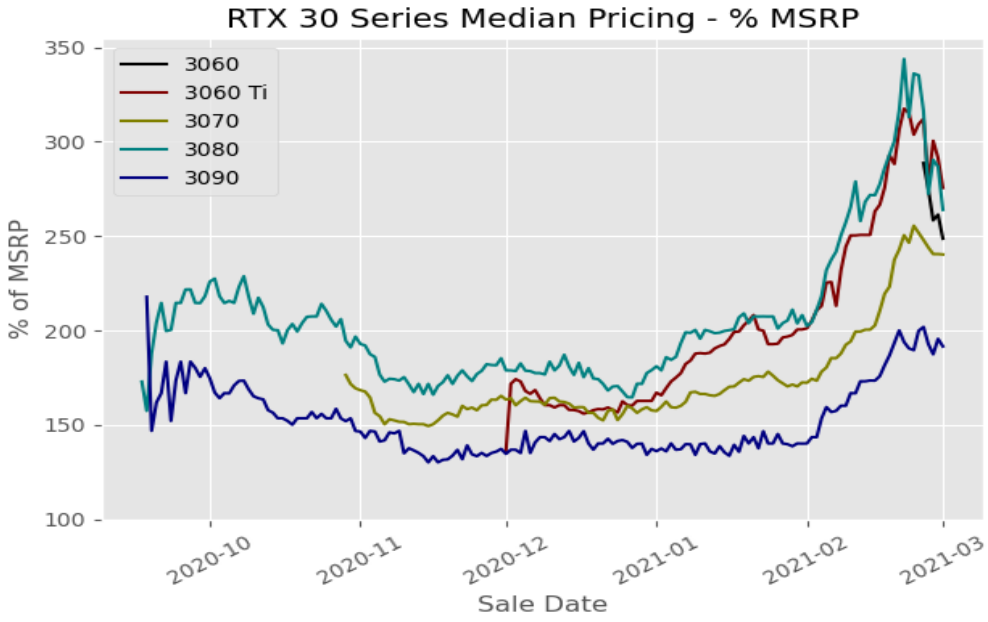


Figure 13. Median pricing of RTX 30 Series on the website of ebay (Kan 2021a).

6 PROPOSED SOLUTIONS FOR NVIDIA

In this section, strategic approaches are discussed that are considered being effective in response to the experienced risks. It is necessary to highlight the importance of Supply Chain Resilience (SC Resilience), as the discipline derived from SCRM and SCM. Ideally, a resilient supply chain is expected to be prepared for disturbances, and it is able to respond and recover from negative events. In addition, it is able to steadily continue their operation in a reasonable cost and time. According to Jüttner & Maklan (2011) there is an identifiable relationship between Supply Chain Vulnerability (SCV), SC Resilience and SCRM, and these concepts go hand in hand with each other. SCM decisions can be made in consideration with SC Resilience, and the use of strategies can result in less exposure to risk or the impact of the disruptive event. Ribeiro & Barbosa-Povoa (2018, 116) notes that SCRM has to deal with several challenges and often poses insufficient information which renders traditional methods of managing risks might be inadequate in the supply chain context. SC Resilience tools and knowledge should be taken into consideration with the traditional methods.

Besides supply chain resilience, the concept of supply chain agility (SCA) can be applied as an extension. SCA can be defined as a strategic capability that enables a firm to quickly to respond to external and internal uncertainties, disruptions and convert them into competitive opportunities by utilizing assets, knowledge and relationships (Ngai et al 2011, 235; Shukor et al 2020,5).
Gligor et al. (2019) distinguishes SCA from SC resilience by highlighting three themes (Figure 14.):

- Quickly changing direction: In case of sudden changes in the market, the firm is able to strategically and rapidly respond in a cost-efficient manner with co-operation with partners (Ngai et al 2011, 234).
  This approach could be applied as working with SEC's and AIB partners in order to secure an interrupted supply flow to the production facilities.

- Empowering the customer: Recognizing the central role of customer in the supply chain and adjusting product and services to meet their changing expectations (Gligor et al 2019, 9).

  NVIDIA's recognizes the importance of the gaming and their customer base, therefore prioritizes the availability of products to them.

- Integrating processes: Supply chain integration involves close alignment and coordination with suppliers and customers within a firm's supply chain, sharing activities such as demand forecast, inventory and production plans (Shukor et al 2020, 5).

  This would mean higher visibility for NVIDIA in their supply chain, quick allocation of resources with prioritization towards customers.

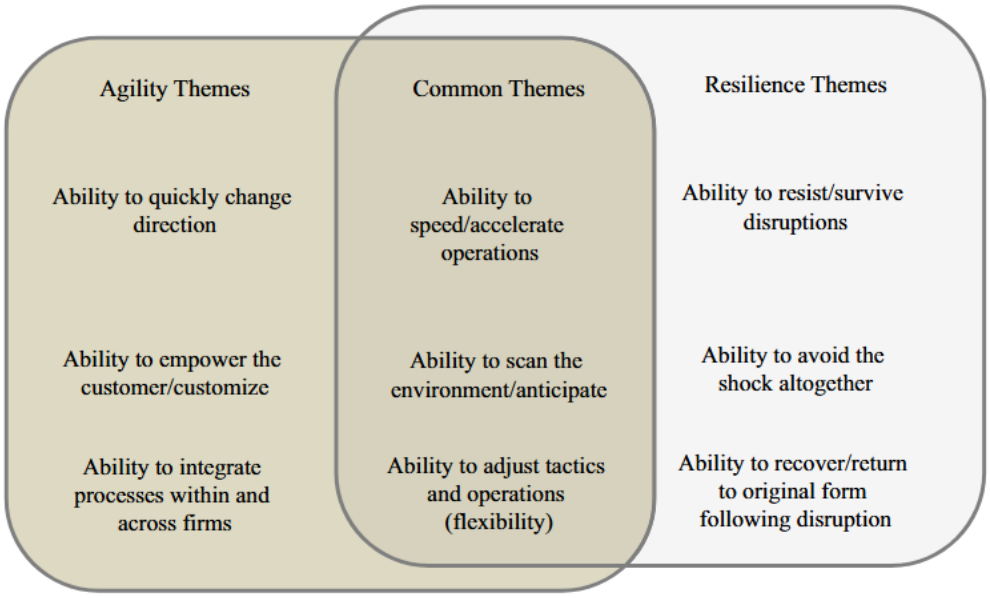


Figure 14. Distinguishing and common themes across SCA and SC resilience (Gligor et al 2019, 14)

Whilst SC resilience is mainly associated with disruptive events and risk management, SCA is often mentioned in lean management. Effective SCA is something that organization should strive for due to benefits provides not only in disruptive scenarios, but it has positive influence on competitive advantage and business performance as well (Al Humdan, Shi & Behnia 2020, 307).

In the followings, selected resilience efforts and strategies are presented with respect to the risk categories and recognized patterns in the results. It is important to note that the effects of the presented strategies can reflect on other dimensions, not limited to only one category. For example, responsive pricing can regulate demand and consequently reduce pressure on supplier and transportation of goods, hence both supply risk and demand risk are addressed to a certain extent.

6.1 Addressing transportation difficulties

It is indicated that logistics and supply chain networks are needed to be redesigned in order to limit the consequences of disruptive event and exploited vulnerability (Chowdhury et al. 2021, 13).

One network type seemed to be effective for disruption management is the hub-and-spoke network with routing flexibility (Esmizadeh & Mellat Parast 2021, 17). Hub-and-spoke network is described as connecting suppliers and customers via indirect links to hub centers, instead of using several directing links (Point-to-Point) (Website of The Geography of Transport Systems, 2021). Hub facilities act as switching and transhipment points for example airlines and cargo delivery systems. Three types of hub networks are distinguished in the literature (Figure 15.):

- Pure hub-and-spoke network: products go through a single hub center
- Hybrid hub-and-spoke network: delivery process includes more hub centers
- Hierarchical hub-and-spoke network: higher level hubs provide air transportation, and lower-level hubs provide ground transportation

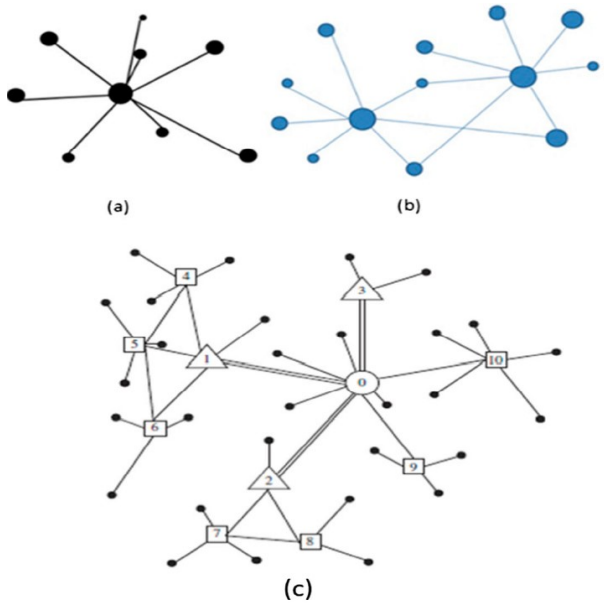


Figure 15. a) pure network, b) hybrid, c) hierarchical hub-and-spoke network (Esmizadeh & Mellat Parast 2021, 8)

Esmizadeh & Mellat Parast (2021, 17) suggests these network design for shipping companies (e.g. FedEx, UPS), due to the storing possibilities over long distances as it reduces travel cost with economies of scale. It is also considered to be more flexible than point-to-point network regarding demand fluctuation because of the storing feature, but on the expense of inventory and labor cost. In a point-to-point network, the supplier locations are connected directly even if the route may not be direct, and without any mediation services (i.e hub) that would interrupt the connections (Website of The Geography of Transport Systems, 2021).
They also mention the vulnerability to disruption, as disruption in one hub center interrupts the flow of goods to the destination points assigned to the hub. It is possible to avoid the impact, if there are multiple hub centers and the load can be transferred from the disrupted one to an unaffected one. Therefore, routing flexibility has to be included in this type of network design, which allows alternate routing between the origin and the destination utilizing the available hubs.

For example, NVIDIA could benefit from the hub-network design is creating a distribution hub in Shanghai. The major AIB partners, ASUS and MSI could be supplied through the hub. If necessary, products can be transport using trucks to the Shenzhen

factories, and shipped to Taipei. The road freight transportation mode is more advantageous than shipping during pandemic due to the less congestion on the road and faster as well, which is an important factor when the demand is high. If there is already a logistical hub for AIB distribution in Hong Kong, the second hub can be still considered in order to bypass the movement restriction between the city and mainland China and a backup inventory to secure material flow to the factories. In addition, it enables flexibility of transportation modes, as it is Shanghai International Airport is located nearby if a shipment needs to be rushed.
However, NVIDIA must calculate the higher cost of inventory and transportation that come with operating a distribution center. Furthermore, political risk is also need to be considered due to US-China trade war already affected SEC's operation (Website of Samsung, 2021).

Hub-and-spoke type of network also enables the implementation of faster delivery modes such as air transport. Emergency transportation is necessary to mitigate the immediate effect of the pandemic (Chowdhury et al. 2021, 15). For example, Samsung rushed the component supply from China to the Korean facilities by choosing air transport instead of trucking, after lockdowns and restrictions had gotten announced (Patchett 2020).

Controlling transportation costs and fair policies are mentioned as well for allocating resources by Chowdhury et al. (2021, 15), which corresponds to the United Nations Conference on Trade and Development (UNCTD) policy briefing (2021) that highlights the following key points:

- Facilitation and digitalization of trade: Custom procedures, port operations, and ships movement are required to be performed with reduced physical contact. Facilitation solutions proposed by the UNCTD for maintaining connectivity are dependent on the digitalization of trade processes.
- Tracking and tracing: Transparency and collaboration in the global maritime supply chain needs to be promoted such port call optimization and liner schedules, and potential market power abuse is needed to be monitored and prevented if necessary.

- Competition in maritime transport: Policymakers need to reinforce national competition authorities in the maritime transport, so the operations are in compliance with regulations and they have the means to provide the regulatory oversight. For example, shippers have complained about the high fright rates and empty containers, indicating power abuse by the carriers. The issue is undergoing investigation by the competition authorities.

As a summary, high freight rates issue is not something that NVIDIA could specifically address. However, their supply chain could raise awareness by informing regulatory bodies to introduce sanctions or price-cap regulation to limit how much a carrier could charge for their services.

6.2 Facilitating production

In response to copy with high demand and shortage of raw material supply, Paul and Chowdhury (2020) created a production recovery plan in manufacturing supply chains. The plan includes recovery strategies and optimized production plan to manage the dual disruptions. The recovery model has two pillars (Paul & Chowdhury, 2020, 6):

- Increase in production capacity: It can be achieved by increasing number of shits, investing in additional machinery, utilizing idle time and extra human resources. The additional cost of increasing capacity is considered in the model.
- Emergency sourcing and collaboration: Backup suppliers or new suppliers are needed to be established to increase the raw material supply by leveraging supply chain partners. Emergency sourcing cost is considered in the model, as the price of raw material should be higher than usual.

They developed a constrained mathematical model which is designed to determine the optimal production plan in the recovery window meanwhile maximizing the total profit. A lost sales cost function is also included for unmet demand to ensure meeting the increased demand. Their study contains two mathematical models (Paul & Chowdhury, 2020, 6):

- Ideal production system – Calculation of Economic Production Quantity (EPQ)

- Model for recovery plan - COVID -19 related parameters e.g. average cost of increasing production, sourcing cost per unit of raw material etc. The recovery plan includes equations for different costs e.g. capacity increase, sourcing, lost sales etc.

The models were tested by using hypothetical data, comparing them to a no-action taken scenario. Summarizing findings of their study, simultaneous implementation of the strategies resulted in positive effect on recovery. Furthermore, improvement in total profit was a consequence of using the models as well (Paul & Chowdhury, 2020, 12).

This model should support SEC's production to meet the demand. Although, SEC has to address two crucial elements before the model could be placed into action:

- Production capacity: SEC announced that they would expand their foundry capacity with a new production in Pyeongtaek. It is expected to start operating in June, 2021 (Website of Samsung 2021; Eun-jin 2021b).
  In the long term, they are planning to build an additional foundry in Austin, Texas, USA. The facility is expected to go into production in the second half of 2023 (Kim, S. 2021).
- Supplier diversification: It is reported Samsung begun sourcing silicon wafers from SK Siltron, and hydrogen fluoride (chemical in chip production) from Soulbrain, which are both South Korea based companies (Boe-eun 2021). The sourcing policy is not known, whether dual-sourcing is in place or they act as backup suppliers.

In addition, Japanese chip raw material producers have also been pressured to increase their supply capacity in South Korea (SK) e.g. Tokyo Ohka Kogyo doubled their production capacity in their Korean factory; Daikin Industries will build a factory in SK too. It is suggested that Japanese restriction on chemical material export to SK is one of the reasons behind the investment. Furthermore, South Korean promotes domestic production and provides incentives (subsidies, tax breaks) to the industry (Website of Nikkei Asia, 2021).

SEC's decision to source from local suppliers and shortening supply chain networks is consistent with literature suggestions of nearshoring and introducing backup suppliers to reduce the exposure to risks (Chowdhury et al. 2021; Paul & Chowdhury, 2020; van Hoek 2020).

Nearshoring or back shoring production facilities refers to shortening supply chains, utilizing a combination of domestic production and international trade to reduce vulnerability (Chowdhury et al. 2021, 16).

Backup suppliers mean the company provides orders for the suppliers in turns, if there is disruption in the first delivery, then the second supplier steps in to compensate (Golmohammadi & Hassini 2020, 11). The involvement of the backup supplier highly depends on the disruptive scenario at the primary supplier, and it should be chosen according to the capacity and lead time as it affects the total cost of production e.g. limited capacity with no lead time, or increased capacity with positive lead time. The capacity flexibility of the backup supplier is considered to be effective in disruption scenarios, but keeping varying lead time in my mind (Golmohammadi & Hassini 2020, 14).

6.3 Demand management

Sodhi and Tang (2012, 212) describes strategies to manipulate uncertain demand with consideration of uncertain supply.

- Demand postponement: customers are required to accept shipments at a later time (Sodhi and Tang 2012, 217). This is commonly known as "pre-order" method, already implemented at several retailers.
- Shifting demand across market: Utilizing information to determine the pricing and ordering decisions. Throughout the seasons, the company collects selling

data from primary and secondary markets, and improves accuracy of forecasting by modifying stocking level and selling price by allocating resources from one to another. It is expected to establish optimal pricing and ordering decisions for both markets (Sodhi and Tang 2012, 218). This method can be useful for NVIDIA's to manage data center and gaming market segment.

- Shifting demand across products:
    - Product substitution: selling product with similar features. This method has been applied by NVIDIA with crypto mining graphics card mentioned above. They also relaunched production of an older graphics card GTX 1650, which is efficient for mining, therefore they anticipate that only video gamers would be interested (Zhiye 2021).
    - Product bundling: when products are sold in bundles, customers are expected to respond reluctantly to purchase when they see the higher price as they are forced purchase all the products within the bundle. This method is also used at retailers e.g. RTX 3070 is built in a whole personal computer (PC). The customers who already own a PC, and they are only interested buying the graphics card itself, will be reluctant to order the PC due to the other components included.

Golmohammadi and Hassini (2020, 3) highlights simultaneous pricing and lot-sizing method, in the form of cross functional integration sales and operations planning. One of the main strategies they mention is responsive pricing, where the company uses price as a tool to practice control over demand. Strategies such as shifting demand across product can be also considered as responsive pricing e.g. offering discounts for products that have components sourced from different suppliers, that are unaffected by the disruptive event. They also mention that in case of a disruptive event, the pricing policy follows a list-price policy (MSRP) that depends on the level of raw materials and finished product inventory. In case of dual sourcing in disruption context, retailer risks are reduced and leads to a lower selling price. However, applying second suppliers does not consequently mean lower order quantities from the first supplier, as the disruption can be cumulative pandemic (Golmohammadi and Hassini 2020, 3) , which is the case considering the effect of a disruptive event. Therefore, choosing the backup/second supplier need to be carefully performed to ensure reliability.

7 EVALUATION AND CONCLUSION

7.1 Overview

In conclusion, this thesis provided insights to the shortage of NVIDIA's graphics card and its relation to the COVID-19 pandemic. It offered a deeper understanding into supply chain risk management from the perspective of the NVIDIA's shortage, uncovering the nature of supply chain risks and drivers that perceivable in this particular scenario. The proposed managements techniques and concepts are expected to target the mentioned risks, but they can be utilized in the development of customized techniques that are designed to handle individual issues.

Based on the findings, it is reasonable to regard the NVIDIA's graphics card shortage a complex issue which does not only stem from the COVID-19 pandemic. Its supply chain structure contained certain vulnerabilities, that later have become risks due to the triggering event i.e pandemic. The direct contribution of pandemic to the risks is the limitation in workforce as people are forced to stay at home with the sickness to avoid spreading the virus. The rest of pandemic effects are restrictions that authorities employed to contain the spread of the virus.

The thesis identified supply chain vulnerabilities drivers that made NVIDIA's supply chain particularly exposed to disruptions. As NVIDIA applies fabless manufacturing and outsources most operations but design and software development, it is difficult to practice high control over these vulnerabilities without reviewing supply chain design variables (Wagner & Bode 2006, 310).

The effects of the shortage reflected as risks in the case, which were categorized based on the selected literature. It was observable that the risks can be differentiated by their sources, but they were still interlinked and one often influences the other e.g. difficult production planning in high-demand fluctuation scenario. The shortage had put a strain on the supply chain and the relationship between the nodes, customers considered the shortage as the supplier's fault (Coberly 2021; Hagedoorn 2020), making it complicated to execute coordinated recovery in the supply chain.

Nevertheless, there are promising management techniques for addressing risks and regain control over supply chain processes. The pandemic related risks have gained a lot of attention from researchers and supply chain professionals, and extensive literature has been established by the scientific community as the thesis demonstrated. There are useful concepts such as supply chain agility and resilience that might gain more attention in the future. It should be noted that several of the articles reviewed in the thesis highlight the necessity of collaborative strategies from the supply chain partners, as addressing problems in a supply chain requires supplier engagement and effective relationship management in mutual projects (Chowdhury et al 2021, 15; Mollenkopf et al. 2020, 2; Paul & Chowdhury 2020, 15; van Hoek 2020, 350).

Furthermore, the pandemic has long-lasting effects in supply chain trends. The shift towards nearshoring, utilizing backup suppliers and overall shortening supply chains are already observable in SEC's reaction to the shortage (Boe-eun 2021; Eun-jin 2021b). These are necessary responds in order to reduce the exposure and ensure uninterrupted material flow (Chowdhury et al. 2021, 21; van Hoek 2020, 351).

The outlook of the semiconductor sector and NVIDIA is bright, as the pandemic facilitated developments of this industry, it has seen above-trend growth, and demand for chip will remain high (Cao & Sundstrom 2021). However, the shortage is expected to last in the near future, no sight of full recovery before 2022-23. The date corresponds to the awaited capacity scales up, when the new foundries are planned to go into operation (Machkovech 2021; Warren 2021b; Website of Samsung 2021).

7.2 Limitation to the thesis

One constraint of the thesis mainly lies in the research process. There might be further underlying factors and effects that are not shared online, or not have been exposed to public, for example information related to how NVIDIA handled the restrictions internally, how effective workers' performance has been during the pandemic etc. For this reason, the list of identified vulnerability drivers and risks might be incomplete.

Despite focusing on scientific and professional articles, there were magazine and newspaper articles processed in the thesis, where there was no alternative. The validity of these sources is questionable and might not be as accurate.
Furthermore, the proposed managements techniques were deduced based on the available information which lacked the specifics of transportation and production. Therefore, they might not be completely suitable for NVIDIA's case and it is most likely need to be further reviewed to be applicable.

7.3 Research opportunities

For future research in this topic, it would be interesting to examine how the planned capacity increase will have impacted the shortage, whether the capacity scales up will be enough to address the problem entirely, or there will have been other changes or implementations besides it. NVIDIA and SEC's are expecting the solution to the shortage from the new production facilities (Kim & King 2021), but there could be additional developments in their operations.

Another topic that should be considered researching is the lean thinking in disruption scenario, whether the foundations of the concept are still as beneficial as during uninterrupted periods, and how SC resilience and agility can be combined with lean practices. There is lack of scientific research, but ongoing dispute over the effectiveness of lean principles after the emergence of the pandemic. In practice, this can be observed at companies that apply lean methods in their operation. Furthermore, Ivanov (2021) developed a conceptual framework so called AURA (Active Usage of Resilience Assets) where lean and resilience models are emphasized, and transforms resilience as an active and value-creating element of firms' operations, while maintaining the advantages of lean thinking. This AURA model can be examined in supply chains and review its applicability.

7.4 Own evaluation of the thesis project

The process of completing the thesis project was a beneficial experience, as the knowledge gained during one's studies had to be utilized to recognize patterns and

create sense from practical events. Searching for relevant sources and materials was quite challenging, especially without any assistance from the case company. Relying on own resources revealed difficulties of conducting this type of study, particularly the aspect of working from insufficient amount of material, which can be hard to overcome.

Fortunately, receiving a lot of support and guidance from the thesis supervisor assisted in finding relevancy in the source materials, creating coherence in the text and improve the overall image of the thesis. The supervising factor was also motivating and helped to stay on track with the tasks.

Even though sticking to the initially planned schedule was not achievable, the duration of the thesis project did not overextend extremely and it was completed in reasonable interval.

REFERENCES

Al Humdan, Eias, Shi, Yangyan & Behnia, Masud 2020. Supply chain agility: a systematic review of definitions, enablers and performance implications. International Journal of Physical Distribution & Logistics Management. Emerald Publishing Limited, 50(2), 287–312. Referred 28.5.2021. DOI: 10.1108/IJPDLM-06-2019-0192.

Attinasi, Maria Grazia, Bobasu, Alina & Gerinovics, Rinalds 2021. What is driving the recent surge in shipping costs? European Central Bank. Referred 18.5.2021. https://www.ecb.europa.eu/pub/economic-bulletin/focus/2021/html/ecb.ebbox202103_01~8ecbf2b17c.en.html.

Boe-eun, Kim 2021. Japanese suppliers lose out as Samsung engages local vendors. Referred 27.5.2021. https://www.koreatimes.co.kr/www/tech/2021/03/129_305406.html

Bryce, C., Ring, P., Ashby, S. & Wardman, J. K. 2020. Resilience in the face of uncertainty: early lessons from the COVID-19 pandemic. Journal of Risk Research. Routledge, 23(7–8), 880–887. Referred 8.6.2021. DOI: 10.1080/13669877.2020.1756379.

Cao, Yishan & Sundstrom, Geraldine 2021. Global Chip Shortage: The Winners and Losers. Pacific Investment Management Company LLC. Referred 8.6.2021. https://europe.pimco.com/en-eu/insights/blog/global-chip-shortage-the-winners-and-losers

Casas, Alex 2021a. Decreasing NVIDIA & AMD Shipments Are Causing Partners Such As MSI & ASUS To Raise The Prices Of GPUs. Wccftech Referred 8.6.2021. https://wccftech.com/msi-increase-graphics-cards-prices-high-demand-low-gpu-shipments-nvidia-amd/

Casas, Alex 2021b. Newegg Shuffle - May 21st: NVIDIA Takes Center Stage With Multiple RTX 3070 and RTX 3080 Graphics Cards Available In Today's Shuffle. Wccftech Referred 8.6.2021. https://wccftech.com/newegg-shuffle-may-21st-nvidia-takes-center-stage-with-multiple-rtx-3070-and-rtx-3080-graphics-cards-available-in-todays-shuffle

Casas, Alex 2021c. Newegg Shuffle: NVIDIA GeForce RTX 3060, 3070, 3080, & 3090 Graphics Cards Are All Available In Today's Shuffle. Wccftech Referred 8.6.2021. https://wccftech.com/newegg-shuffle-nvidia-geforce-rtx-3060-3070-3080-3090-graphics-cards-are-all-available-in-todays-shuffle

Cheng, Lilian, Kang-Chung, Ng, Yau, Cannix & Low, Zoe 2020. Hong Kong third wave: health officials race to contain port outbreak as nearly half of 74 new Covid-19 cases tied to container terminal cluster. South China Morning Post Referred 28.5.2021. https://www.scmp.com/news/hong-kong/health-environment/article/3097545/hong-kong-third-wave-latest-infections-linked

Chowdhury, Priyabrata, Paul, Sanjoy Kumar, Kaisar, Shahriar & Moktadir, Md Abdul 2021. COVID-19 pandemic related supply chain studies: A systematic review. Transportation Research Part E: Logistics and Transportation Review. Referred 28.5.2021. https://doi.org/10.1016/j.tre.2021.102271

Christopher, Martin & Peck, Helen 2004. Building the Resilient Supply Chain. The International Journal of Logistics Management. Emerald Group Publishing Limited, 15(2), 1–14. Referred 28.5.2021. DOI: 10.1108/09574090410700275.

Chua, Grace, Yuen, Kum Fai, Wang, Xueqin & Wong, Yiik Diew 2021. The Determinants of Panic Buying during COVID-19. International Journal of Environmental Research and Public Health. Multidisciplinary Digital Publishing Institute, 18(6), 3247. Referred 27.5.2021. DOI: 10.3390/ijerph18063247.

Coberly, Cohan 2021. Asus says GPU shortages could be a result of low ”upstream” production yields from Nvidia. TechSpot Referred 8.6.2021. https://www.techspot.com/news/89043-asus-gpu-shortages-could-result-low-upstream-production.html

Dente, S.M.R. & Hashimoto, S. 2020. COVID-19: A pandemic with positive and negative outcomes on resource and waste flows and stocks. Resources, Conservation, and Recycling. 161, 104979. Referred 28.5.2021. DOI: 10.1016/j.resconrec.2020.104979.

El Abdellaoui, Mohamed & Youssef, M 2017. Supply Chain Risk Management: Empirical Analysis of Logistic Performance in Relation to Macro and Micro Risks Dimensions. Journal of Business Studies Quarterly. 9, 32–51. Referred 27.5.2021. DOI: 10.2139/ssrn.3611402.

Epstein, Adam 2020. Game on: How COVID-19 became the perfect match for gamers. World Economic Forum Referred 18.5.2021. https://www.weforum.org/agenda/2020/09/covid19-coronavirus-pandemic-video-games-entertainment-media/

Esmizadeh, Yalda & Mellat Parast, Mahour 2021. Logistics and supply chain network designs: incorporating competitive priorities and disruption risk management perspectives. International Journal of Logistics Research and Applications. Referred 18.5.2021. Taylor & Francis, 24(2), 174–197.

Eun-jin 2021a. Order Overload at TSMC to Benefit Samsung Electronics. Business Korea Referred 18.5.2021. http://www.businesskorea.co.kr/news/articleView.html?idxno=60899

Eun-jin, Kim 2021b. Samsung Electronics to Start Operating Foundry Line in Pyeongtaek in June - Businesskorea Referred 28.5.2021. http://www.businesskorea.co.kr/news/articleView.html?idxno=64945

Evanson, Nick 2020. Anatomy of a Graphics Card. TechSpot Referred 2.5.2021. https://www.techspot.com/article/1988-anatomy-graphics-card/

Fan, Yiyi & Stevenson, Mark 2018. A review of supply chain risk management: definition, theory, and research agenda. International Journal of Physical Distribution & Logistics Management. Emerald Publishing Limited, 48(3), 205–230. Referred 25.4.2021. DOI:10.1108/IJPDLM-01-2017-0043.

Fonseca, Luis Miguel & Azevedo, Americo Lopes 2020. COVID- 19: outcomes for Global Supply Chains. Management & Marketing. Sciendo, 15(s1), 424–438. Referred 8.6.2021. DOI:10.2478/mmcks-2020-0025

Garnett, Philip, Doherty, Bob & Heron, Tony 2020. Vulnerability of the United Kingdom's food supply chains exposed by COVID-19. Nature Food. Nature Publishing Group, 1(6), 315–318. Referred 8.6.2021. DOI: 10.1038/s43016-020-0097-7.

Gligor, David, Gligor, Nichole, Holcomb, Mary & Bozkurt, Siddik 2019. Distinguishing between the concepts of supply chain agility and resilience: A multidisciplinary literature review. The International Journal of Logistics Management. Emerald Publishing Limited, 30(2), 467–487. Referred 28.5.2021. DOI: 10.1108/IJLM-10-2017-0259.

Goodman, Peter S., Stevenson, Alexandra, Chokshi, Niraj & Corkery, Michael 2021. 'I've Never Seen Anything Like This': Chaos Strikes Global Shipping. The New York Times. Referred 25.4.2021. https://www.nytimes.com/2021/03/06/business/global-shipping.html

Gupta, Varun, Ivanov, Dmitry & Choi, Tsan-Ming 2021. Competitive pricing of substitute products under supply disruption. Omega. 101, 102279. Referred 28.5.2021. DOI: 10.1016/j.omega.2020.102279.

Hagedoorn, Hilbert 2020. NVIDIA: Ampere RTX 30 Stock Issues Is not only based on GPU shortages. Guru3D.com. Guru3D Referred 18.5.2021. https://www.guru3d.com/news-story/nvidia-ampere-stick-issues-is-not-only-based-on-gpu-shortages.html

Hagedoorn, Hilbert 2021. NVIDIA and AMD Graphics card shortages to last thoughout H1 2021. Guru3D.com. Guru3D Referred 8.6.2021. https://www.guru3d.com/news-story/nvidia-and-amd-graphics-card-shortages-to-last-thoughout-h1-2021.html

Heckmann, Iris, Comes, Tina & Nickel, Stefan 2015. A critical review on supply chain risk – Definition, measure and modeling. Omega. 52, 119–132. Referred 25.4.2021. DOI: 10.1016/j.omega.2014.10.004.

Ho, Joshua 2014. An Introduction to Semiconductor Physics, Technology, and Industry. Anandtech Referred 30.4.2021. https://www.anandtech.com/show/8223/an-introduction-to-semiconductor-physics-technology-and-industry

van Hoek, Remko 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. Emerald Publishing Limited. Referred 14.5.2021. DOI:10.1108/IJOPM-03-2020-0165

Hollister, Sean 2021a. Sure enough, EVGA and Zotac have raised prices on the Nvidia RTX 3080 and beyond. The Verge Referred 28.5.2021. https://www.theverge.com/2021/1/13/22228470/nvidia-evga-zotac-raise-prices-rtx-3080-3070-3060-3090

Hopkin, Paul 2017. Fundamentals of risk management : understanding, evaluating and implementing effective risk management. New York: Kogan Page Ltd. Referred 20.5.2021. https://samk.finna.fi/Record/samk.991273746605968.

Hwang, Jeong-soo 2020. Samsung clinches 2nd deal to make Nvidia's latest gaming chips. The Korea Economic Daily Global Edition. Referred 18.5.2021. https://www.kedglobal.com/newsView/ked202012170015

Ivanov, Dmitry 2021. Lean resilience: AURA (Active Usage of Resilience Assets) framework for post-COVID-19 supply chain management. The International Journal of Logistics Management. ahead-of-print. Referred 11.6.2021. DOI: 10.1108/IJLM-11-2020-0448.

Ivanov, Dmitry & Das, Ajay 2020. Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: a research note. International Journal of Integrated Supply Management. 13, 90. Referred 28.5.2021. DOI: 10.1504/IJISM.2020.107780.

Jüttner, Uta 2005. Supply chain risk management: Understanding the business requirements from a practitioner perspective. The international journal of logistics management. Emerald Group Publishing Limited, 16(1), 120–141. Referred 25.4.2021. DOI: 10.1108/09574090510617385.

Jüttner, Uta & Maklan, Stan 2011. Supply chain resilience in the global financial crisis: an empirical study. Supply Chain Management: An International Journal. Emerald Group Publishing Limited, 16(4), 246–259. Referred 18.5.2021. DOI: 10.1108/13598541111139062.

Kan, Michael 2021a. Prices for Nvidia RTX 3000 Graphics Cards Are Getting Ridiculous on eBay. PCMAG Referred 18.5.2021. https://www.pcmag.com/news/prices-for-nvidia-rtx-3000-graphics-cards-are-getting-insane-on-ebay

Kan, Michael 2021b. RTX 3080 Ti Founders Edition Was in (Very) Short Supply at Best Buys Across the US | PCMag Referred 8.6.2021. https://www.pcmag.com/news/rtx-3080-ti-founders-edition-was-in-very-short-supply-at-best-buys-across

Keane, Michael & Neal, Timothy 2021. Consumer panic in the COVID-19 pandemic. Journal of Econometrics. 220(1), 86–105. Referred 28.5.2021. DOI: 10.1016/j.jeconom.2020.07.045.

Khan, Omera & Zsidisin, George A. 2011. Handbook for Supply Chain Risk Management: Case Studies, Effective Practices and Emerging Trends. Ft. Lauderdale, FL: J. Ross Publishing. Referred 25.4.2021.

Kim, Sohee & King, Ian 2021. Samsung Considers $10 Billion Texas Chipmaking Plant, Sources Say. Bloomberg Referred 11.6.2021. https://www.bloomberg.com/news/articles/2021-01-22/samsung-is-said-to-consider-10-billion-texas-chipmaking-plant

Kim, Sohee 2021. Samsung Details Plans for $17 Billion Chip Facility in U.S. Bloomberg Referred 28.5.2021. https://www.bloomberg.com/news/articles/2021-03-03/samsung-details-plans-for-17-billion-chip-facility-in-u-s

Kim, Tae 2021. Nvidia Risks a Reckoning by Catering to Crypto Miners. Bloomberg Referred 18.5.2021. https://www.bloomberg.com/opinion/articles/2021-04-14/nvidia-risks-a-reckoning-as-crypto-miners-deprive-gamers-of-graphics-cards

Kumar, Aalok, Luthra, Sunil, Mangla, Sachin Kumar & Kazançoğlu, Yiğit 2020. COVID-19 impact on sustainable production and operations management. Sustainable Operations and Computers. 1, 1–7. Referred 28.5.2021. DOI: 10.1016/j.susoc.2020.06.001.

Liu, Nicolle & Hale, Thomas 2021. China's exporters hit by global shortage of shipping containers. Financial Times Referred 18.5.2021. https://www.ft.com/content/71818164-9f74-48ad-af10-88c3acf30190

Ma, Kwan-Chen 2017. Happy New Year Nvidia (NASDAQ:NVDA). SeekingAlpha Referred 2.5.2021. https://seekingalpha.com/article/4134093-happy-new-year-nvidia

Ma, Kwan-Chen 2021. Nvidia (NASDAQ:NVDA): The Post-COVID Outlook. SeekingAlpha Referred 18.5.2021. https://seekingalpha.com/article/4408049-nvidia-post-covid-outlook

Machkovech, Sam 2021. Intel, Nvidia, TSMC execs agree: Chip shortage could last into 2023. Ars Technica Referred 8.6.2021. . https://arstechnica.com/gadgets/2021/04/intel-nvidia-tsmc-execs-agree-chip-shortage-could-last-into-2023/

Mollenkopf, Diane A., Ozanne, Lucie K. & Stolze, Hannah J. 2020. A transformative supply chain response to COVID-19. Journal of Service Management. Emerald Publishing Limited, 32(2), 190–202. Referred 28.5.2021. DOI: 10.1108/JOSM-05-2020-0143.

Netland, Torbjørn 2021. Just-in-Time and the Covid pandemic. Planet Lean Referred 8.6.2021. https://planet-lean.com/just-in-time-pandemic/

Ngai, Eric W. T., Chau, Dorothy C. K. & Chan, T. L. A. 2011. Information technology, operational, and management competencies for supply chain agility: Findings from case studies. The Journal of Strategic Information Systems. 20(3), 232–249. Referred 28.5.2021. DOI: 10.1016/j.jsis.2010.11.002.

Park, YoungWon, Hong, Paul & Roh, James Jungbae 2013. Supply chain lessons from the catastrophic natural disaster in Japan. Business Horizons. 56(1), 75–85. Referred 25.4.2021. DOI: 10.1016/j.bushor.2012.09.008.

Patchett, Lucy 2020. How much support has Samsung given suppliers during Covid? Supply Management Referred 18.5.2021. https://www.cips.org/supply-management/news/2020/october/how-much-support-has-samsung-given-suppliers-during-covid/

Pathak, Vibha, Jena, Bijayini & Kalra, Sanjay 2013. Qualitative research. Perspectives in Clinical Research. 4(3), 192. Referred 17.6.2021. DOI: 10.4103/2229-3485.115389.

Paul, Sanjoy Kumar & Chowdhury, Priyabrata 2020. A production recovery plan in manufacturing supply chains for a high-demand item during COVID-19. International Journal of Physical Distribution & Logistics Management. Emerald Publishing Limited, 51(2), 104–125. Referred 18.5.2021. DOI: 10.1108/IJPDLM-04-2020-0127.

Ribeiro, João Pires & Barbosa-Povoa, Ana 2018. Supply Chain Resilience: Definitions and quantitative modelling approaches–A literature review. Computers & Industrial Engineering. Elsevier, 115, 109–122. Referred 18.5.2021. DOI: 10.1016/j.cie.2017.11.006.

Schwerdtfeger, Max 2020. Port of Hong Kong struggles under strain of COVID-19. Port Technology International. Referred 28.5.2021. https://www.porttechnology.org/news/port-of-hong-kong-struggles-under-strain-of-covid-19/

Sherman, Erik 2020. 94% of the Fortune 1000 are seeing coronavirus supply chain disruptions. Fortune. Referred 25.4.2021. https://fortune.com/2020/02/21/fortune-1000-coronavirus-china-supply-chain-impact

Shukor, Ahmad Azwan Ahmad, Newaz, Md. Shah, Rahman, Muhammad Khalilur & Taha, Azni Zarina 2020. Supply chain integration and its impact on supply chain agility and organizational flexibility in manufacturing firms. International Journal of Emerging Markets. Referred 28.5.2021. DOI: 10.1108/IJOEM-04-2020-0418.

Sodhi, ManMohan S. & Tang, Christopher S. 2012. Managing Supply Chain Risk. New York: Springer-Verlag. Referred 25.4.2021. DOI: 10.1007/978-1-4614-3238-8.

Suh, Jee Young & Kim, Yong Jin 2009. Logistics lean integration strategies: case study of Samsung Electronics LCD inbound logistics. Journal of International Logistics and Trade. Jungseok Research Institute of International Logistics and Trade, 7(1), 107–116. Referred 8.6.2021. DOI: 10.24006/jilt.2009.7.1.107.

Tang, Ou & Musa, S. Nurmaya 2011. Identifying risk issues and research advancements in supply chain risk management. International journal of production economics. Elsevier, 133(1), 25–34. Referred 24.5.2021. DOI: 10.1016/j.ijpe.2010.06.013.

Teherani, Arianne, Martimianakis, Tina, Stenfors-Hayes, Terese, Wadhwa, Anupma & Varpio, Lara 2015. Choosing a Qualitative Research Approach. Journal of Graduate Medical Education. 7(4), 669–670. Referred 17.6.2021. DOI: 10.4300/JGME-D-15-00414.1.

Thun, Jörn-Henrik & Hoenig, Daniel 2011. An empirical analysis of supply chain risk management in the German automotive industry. International journal of production economics. Elsevier, 131(1), 242–249. Referred 25.5.2021. DOI: 10.1016/j.ijpe.2009.10.010

United Nations Conference on Trade and Development 2021. Container shipping in times of COVID-19: Why freight rates have surged, and implications for policymakers. United Nations Referred 18.5.2021. https://unctad.org/system/files/official-document/presspb2021d2_en.pdf

Wagner, Stephan M. & Bode, Christoph 2006. An empirical investigation into supply chain vulnerability. Journal of purchasing and supply management. Elsevier, 12(6), 301–312. Referred 4.6.2021. DOI: 10.1016/j.pursup.2007.01.004

Wagner, Stephan M. & Neshat, Nikrouz 2010. Assessing the vulnerability of supply chains using graph theory. International Journal of Production Economics. Elsevier, 126(1), 121–129. Referred 4.6.2021. DOI: 10.1016/j.ijpe.2009.10.007

Wallis, Keith 2021. International-Ports: China port congestion flares amid pre-CNY rush. The Journal of Commerce Referred 28.5.2021. https://www.joc.com/port-news/international-ports/china-port-congestion-flares-amid-pre-cny-rush_20210210.html?destination=node/3660461

Warren, Tom 2021a. Nvidia is nerfing new RTX 3080 and 3070 cards for Ethereum cryptocurrency mining. The Verge Referred 18.5.2021. https://www.theverge.com/2021/5/18/22441847/nvidia-rtx-3080-3070-ethereum-mining-drivers-limit-cryptocurrency

Warren, Tom 2021b. Nvidia warns the great GPU shortage will continue throughout 2021. The Verge Referred 8.6.2021. https://www.theverge.com/2021/4/15/22385261/nvidia-gpu-shortage-rtx-3080-warning-comments-2021

Waters, Richard 2021. Nvidia earnings boosted by gaming and data centre chip demand. Financial Times Referred 18.5.2021. https://www.ft.com/content/85017fba-fafa-45aa-b5fa-ae11dd0825ba

Website of Advanced Micro Devices 2021. Referred 8.6.2021 https://www.amd.com/

Website of Government of Canada 2013. Referred 2.5.2021. https://www.tbs-sct.gc.ca

Website of MarketLine 2021. Referred 2.5.2021 https://www.marketline.com

Website of Nikkei Asia. Referred 18.5.2021. https://asia.nikkei.com/

Website of Nvidia Corporation. Referred 25.4.2021. https://www.nvidia.com

Website of Organisation for Economic Co-operation and Development- OECD. Referred 18.5.2021. https://www.oecd.org/

Website of PricewaterhouseCoopers (PwC) 2020. Referred 28.5.2021. https://www.pwc.com/

Website of Samsung Electronics. Referred 18.5.2021. https://www.samsung.com

Website of The Chartered Institute of Procurement and Supply. Referred 2.5.2021. https://www.cips.org

Website of The Geography of Transport Systems. Referred 18.5.2021. https://transportgeography.org

Website of Taiwan Semiconductor Manufacturing Company. Referred 18.5.2021. https://www.tsmc.com/english

Website of U.S. Securities and Exchange Commission 2018. Referred 8.6.2021 https://www.sec.gov

Website of World Trade Organization 2021. Referred 18.5.2021. https://www.wto.org/

Website of Wikimedia Commons 2021. Referred 18.5.2021. https://commons.wikimedia.org

Widder, Brandon 2021. Nvidia's RTX 3080 Ti is available online right now (UPDATE: sold out). The Verge Referred 8.6.2021. https://www.theverge.com/2021/6/3/22465644/nvidia-geforce-rtx-3080-ti-stock-gpu-availability-where-to-buy-graphics-card

Xue, Suming 2021. Global console, mobile and PC gaming drives $175B in content revenue in 2020. S&P Global Referred 18.5.2021. https://www.spglobal.com/marketintelligence/en/news-insights/blog/global-console-mobile-and-pc-gaming-drives-175b-in-content-revenue-in-2020

Zhiye, Liu 2021. Nvidia Allegedly Increases GeForce GTX 1650 Supply To Fight GPU Shortage. Tom's Hardware Referred 18.5.2021. https://www.tomshardware.com/news/nvidia-allegedly-increases-geforce-rtx-1650-supply-gpu-shortage