TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

IMPACT OF GLOBAL ELECTRONIC COMPONENT CRISIS ON ESTONIAN ELECTRONICS INDUSTRY SUPPLY CHAINS

GLOBAALSE ELEKTROONIKAKOMPONENTIDE KRIISI MÕJU EESTI ELEKTROONIKATÖÖSTUSE TARNEAHELATELE

MASTER THESIS

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AUTHOR'S DECLARATION

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THESIS TASK

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Thesis topic:

(in English) Impact of global electronics component shortage on Estonian electronics sector supply chains

(in Estonian) globaalse elektroonikakomponentide kriisi mõju eesti elektroonikatööstusele

Thesis main objectives:

1. To find out how has electronic component crisis impacted electronics industry supply chains from 2019 until 2023
2. To find out new risk mitigation strategies and new ways of working due to the crisis
3. How has the geographical concentration of electronics manufacturing changed
4. To find out how have the inventory levels and production planning principles been impacted due to the crisis

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Literature overview and writing theoretical part	01.03.23
2.	Plan and execute the methodics to conduct study among estonian electronics sector companies	01.04.23
3.	Analysis of results: define new proccesses, ways of woking and analysis overall results	08.05.23
4.	Suggestions for estonian electronics companies supply chains	15.05.23

Language: English **Deadline for submission of thesis:** "22" May 2023 a.

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PREFACE

The author of this thesis is currently working in Estonian electronics manufacturing sector and sees the need for research of current changing electronics supply chain and new ways of working to cope with the existing electronic component crisis, as old principles and ways of working such as just in time and lean manufacturing, warehousing, sourcing, production planning and current methods of leadtime estimations might not fulfill the needs of today*'s* production. Rapidly changing market environment, prolonged leadtimes and price inceases caused by component crisis cause problems with material availability and also big extra costs for the company to be able to source critical components on time. It is important to find out if there are indications for the crisis situation to resolve and what are new the ways of working to cope with the crisis.

Since beginning of the COVID-19 pandemic, demand for electronic devices increased rapidly as they became the most important tool, which enabled people to do education, home-based work and socialising from home. All the social, geopolitical and technical distruptions in the electronics industry raw material supply chains enabled to pinpoint the weaknesses in the electronic component supply chains as the supply chains were not prepared to face such impactful changes. It is also important to highlight the global microchip crisis that started in 2020 and study the effects of it as it is part of the component crisis.

Future supply chains and production need to be ready for another crisis or next impacts of the current one. Future instability can be caused by events such as global political instability, natural disasters, health crisis, fire accidents, price and leadtime fluctuations and effects of the climate change. Currently critical electronics materials production is geographically concentrated, which makes it difficult to mitigate the risks.

As a result of thesis, a risk mitigation strategy suggestions are created to help electronics sector companies to cope with the crisis, as well as an overview of the changes in the sector since beginning of the crisis (2019), overview of supply chain, production and inventory planning strategies and insight to the current changes in concentration of global electronics manufacturing and production.

Keywords: supply chain management, electronics industry, electronic component crisis, risk management, inventory management, production planning, change management, master thesis.

List of abbreviations and symbols

e-SCM – electronic supply chain management system
SCM – supply chain management
REE – rare earth elements
IIOS - Internet-based interorganizational system
EDI – electronic data interchange
IS – info system
TOE – technical-environmental-organizational
ERP – enterprise resource planning system
SCRM – supply chain risk management system
FTA – free trade agreement
Global South – Term generally used to identify countries in the regions of Latin America, Africa, Asia and Oceania
GDP – gross domestic product
JIS – Just-in-sequence. Inventory strategy for delivery of the right products, in the right quantity, at the right time, to the right place and also in the right order or sequence
JIT – Just-in-time. Inventory management method in which goods are received from suppliers only as they are needed
MTO – Make to order. Business production strategy that typically allows consumers to purchase products that are customized to their specifications
ETO – Engineer to order. A product is engineered and produced after an order has been received according to specifics of the customer
EMS – electronic manufacturing services
HHS – Health and human services
GPN – Global production network
CNS – coupled network strtegy
GPS - global positioning system
RFI – radio frequency identification
AI – artificial inteligence

1. INTRODUCTION

The electronic component crisis started in 2019 when COVID-19 pandemic occurred. The crisis tested the strength, adaptiveness and readiness of the supply chains worldwide. The crisis highlighted the weaknesses and strenghths in the risk management systems of electronic manufacturers and forced them to increase inventory levels caused by stockpiling and panic-buying. Leadtimes, availability and price of various components increased rapidly, for example for microchips the price incease was approximately five times. Since the pandemic forced people to study and work from home, the demand of electronic products increased supported by growth in technology sector such as telecommunications and automotive sector.

Since the crisis is still ongoing and involves impact with large extent worldwide, the research topic is relatively new and needs more research than there is available as of now. The aim of current thesis is to contribute to that research.

In regards to the electronics sector, it is important to highlight the global chip crisis, which caused extreme growth in microchip prices and availability issues increasing the leadtime up to 1-3 years for many cases. This issue is complex, because it is impacted by various factors such as production process of the microchips to the rapid increase in demand.

It is important to formulate strategy to cope with the fluctuations of electronics crisis and be better prepared for future disruptions. What is more, in todays environment impacted strongly by inflation, many electronics companies are forced to cut costs to remain profitable and it is not reasonable to make preventable extra spendings on material supply or keep high inventory value and excess stock for non-critical items, which in addition to warehousing costs may become obsolete within one to few years or can decrase in book-value as the market value changes.

The thesis is divided into three parts. In the first part or main body, an extensive understanding of comparative analysis of known data is given. Risk management, metal deficit in electronics, geographical distribution of manufacturing, microchip crisis, Estonian electronics market situation and analysis of impact of the crisis is analysed. In the second part, research methods are planned. In the third part, study among Estonian Electronics sector is coducted, results validated and analysis of the research is done.

To make clear research on the topic, below research questions were concluded to be most important to cover the impact of electronics component shortage. As a result of thesis, a risk mitigation strategy suggestions and are created to help the estonian electronics sector companies to cope with the crisis and adjust their strategy.

- How has electronic component crisis impacted electronics sector supply chains from 2019 until 2023?
- What are the new risk mitigation strategies and ways of working in component sourcing due to the impact of the component crisis?
- How have the warehouse inventory levels and production planning principles changed?
- How geographically concentrated is electronics manufacturing today and how has the crisis changed it?
- To make proposals for estonian elecronics sector supply chains

2. THEORETICAL BACKGROUND

In the theoretical backround author analyses previous studies to give an extensive understanding of comparative literatuure analysis of the global electronic component crisis. Analysis of raw materials, estonian market sector, semiconductor (microchip) crisis, risk mitigation strategies and inventory and production planning optimization methods ways is given.

2.1 Impact of the electronics supply crisis

Demand fluctuation starting from 2019 has caused economic volatility since after economies have opened back again after the lockdowns, due to the material surges the price hikes have been tremendeous and there are no signs of decrease. Also, the locdowns due to pandemic have created increased demand for electronics and have lessened the supply due to closure of mining sites and metal processing units. Also, metal flows have been disrupted due to border closures, trade and logistics difficulties. During times of unstable economics, environmental risks arise, due to environmental regulations being low priority to the countries. (Althaf & Babbitt, 2021)

Early in March 2020, the world's largest 1,000 companies had over 12,000 factories, warehouses and operations in quarantined regions and out of those 3490 were in automotive, industrial and heavy machinery sector. Out of mentioned industrial sector 2730 (78,2%) facilites were located in China. This demonstrates the impact of the crisis and illiustates that companies were not prepared for it despite impact of earlier disasters like Fukushima earthquake and tsunami crisis in 2011. Most companies in 2011 were blindsided by impacts on second-tier and third tier suppliers. They assessed risks quickly only on first-tier suppliers. Supply chain managers faced the risks of single-sourcing and depending only on China. Single-sourcing is often used to meet a cost target, but it can cause extensive extra costs if the risks realise. (Linton & Vakil, 2020) Covid-19 is the longest lasting and most severe crisis in this century. (Rönkkö et al., 2022)

2.1.2 Impact of the crisis to the global supply chains

COVID-19 has affected critical stock availability, a rapid surge in demand, restrrictions in transportation, lockdown policies and the shortage of substantial raw materials has affected the supply chains and the worst-case scenarios supply wise became a reality. A strong dependence on each other in every sector became clearly visible and it emphasized the need for better sectoral coordination. (Xingyu, Amin, et al., 2021)

Regional diversity is the reason why analyzing the risks is crucial to be prepared for regional production disruptions, as well as planning a risk management strategy for each region. For example, to describe COVID-19 crisis affects on the healthcare sector supply, North America has the highest HHS capacity, import, and demand. Next region with highest HHS capacity is the the European Union. Latin America and Oceania have low production capacity and low needs for HHS, while Asia is a major export region for the healthcare resources. Same is applicable for other industries, where it is important to understand the diferent risks associated if the region plays a role of an exporter or importer and the availability and need of local capacity for production. Therefore it is crucial that the manufacturing sector will prepare itself for another potential distruption. (Xingyu, Amin, et al., 2021)

It has been found that key improvements in supply chain efficiency are possible if lean management of resources is done and regional collaboration has been prioritized. Also, managerial strategy decisions play a big role in efficiency of the supply chains. Lean resource allocation strategy reduced the impact of supply chain shortages from 11.9% to 1.11% in North America in HHS sector. In addition, optimization of the digital supply chain strategy and coupled network strategy (CNS), where multiple sources are coupled to regional actors through the lenses of global production networks (GPN) and value chains to make better managerial decisions has been proved to increase the supply chain efficiency. (Xingyu, Amin, et al., 2021)

Advanced automation has unexpectedly speeded up due to COVID-19, the future of labour is moving towards heavy automation of production, distribution, transport and warehousing, as well as retail, finance and administration (Cowen et al., 2010) affecting also white-collar workers, not only the blue-collars as before. (Lee et al., 2018) Labour geographers have had to start investigating the conflictual relationship between human labour and automation, because during the pandemic years, automated infrastructure, computing software and intelligent machines have impacted

the value chains and global production networks (GPN) more than in pre-pandemic years. (Lin, 2022)

Computing software has drastically reduced the need for human intervention in manual documenting, sorting and data organizing activities. In logistics, the types of mechanical automation can be cranes, drones, robots, 3D printing and conveyor belts but in digital areas it involves digital processing of complex information, and the automated handling of evaluative tasks such as speeding up port procedures, object recognition and predictive logistics. (Lin, 2022) Robotics and automation systems are able to extend the capabilities and capacities of infrastructure networks by automation. (Macrorie et al., 2021) Software coding possibilities have progressed from electronic messages such as EDI and automatic signals such as automatic email notifications to a cognitive nonconscious (Hayles, 2017) that is able to bond logistics space with all manners of coded intelligence, which is characterized as an artificial intelligence. (Ash et al., 2018). Automation technologies are also used for purposes of the workforce monitoring, such as tracking and tracing of warehouse personnel through Radio Frequency Identification (RFI) tags, voice recognition systems and global positioning system (GPS). In addition, the movement of cargo between countries is now done by using block-chain technologies and the internet of things to resolve supply chain bottlenecks and ensure safety of the goods. (Zhuckovskaya et al., 2020)

What is more, automation in form of driverless vehicles are aggregate for the first time all the artificial inteligence and advanced physical automation capabilities, ranging from sensors, and prosthetics to algorithmic logic, machine learning and cloud computing. (Herrmann et al.,2018) Mentioned technological revolution is expected to displace more jobs than any other technological revolution has done in the past (Lee, 2018), even as high as 50 per cent in the following two decades (Dengler & Matthes, 2018).

Stockpiling was one of the side effects of the crisis to manufacturing companies as resource shortages caused misinformation and panic buying. (Xingyu, Amin, et al., 2021) Warehouses are full of inventory. Together with economic recession and inflational environment, which is causing the demand to decrease, stock levels are extremely high.

In conclusion, widespread and advanced automation and AI usage in supply chain has occured due to the COVID-19 impacts. More and more jobs are being monitored and

automated using the capabilities of computer programming. Data analysis and sorting has also improved, resulting in shorter overall transportation times. Lean distribution of supplies among global value chains has become more important than ever and usage of the AI is taking methods of current data communication in logistics such as EDI to more complex level.

2.2 Metal deficit and concentration in electronics production

Supply chain crisis impact on precious metals such as gold, rhodium, platinum and palladium leads to price volatility and weakening of environmental regulations, whereas deficit in technology materials such as cobalt and gallium caused supply chain crisis and geopolitical tensions since they require energy intense manufacturing and have the most concentrated geographic production. In that case, solutions could be diversification or recycling. For example Cobalt is produced in the Demographic Republic of Congo. Production sould be shifted from Congo to provide alternative solutions. Cobalt is also the key mineral in lithium-ion batteries. (Althaf & Babbitt, 2021) China is the concentrated producer of the electronics components that are mined locally. As China was the first country to establish a lockdown, the supply chain faced a critical situation. (Gulley, McCullough, & Shedd, 2019) But China is also dependent on other countries in order to get raw material. China relies on imports for 80% of its copper concentrate. The concentrate is sourced from Chile and Peru and needed to make copper metal which is mainly used in power and construction industries. In 2020, miners in Peru had suspended operations, which caused impact for the Chinese smelters. As a result, Chinese copper smelters decreased treatment charges to turn ore into refined copper due to worries about staying competitive due to lack of sufficient supplies. In April 2020 Indonesia banned nickel ore exports and also alternative suppliers in Philipines halted production in order to comply with COVID-19 rules, all this caused nickel ore stock at Chinese ports to be at their lowest since June 2018. As a result, the cheaper alternative of nickel (nickel pig iron) output was cut. There were no issues with bauxite imports from Guinea, also tin concentrate imports from Myanmar were not highly affected, except small pivate producers, who do not have enough tin concentrate in stock to last three to four months. Chromium and manganese ore supplies to China were also not largely affected as of April 2020. Issues appeared with cobalt hydroxide, imports to China from Democratic Republic of Congo decreased 15% as of April 2020. Cobalt

hydroxide is used in electric vehicle batteries. During times when demand for electronic devices increased rapidly due to social distancing, the metals supply chain output decreased due to restrictions and impact due to COVID-19. (Daly & Singh, April 2020) During the 2003-2004 SARS Outbreak, similar crisis to COVID-19 happened in China, where it affected Computer manufacturing sector assembly lines, although it did not clearly have same impact as COVID-19. (Sodhi & Lee, 2007) Geopolitical risks come often from southeast Asia, bacause most of the electronic component mining, refining, manufacturing and assembly is done there. Therefore geographic diversification for high risk materials is a must to grow resilience, if there wont be good substitutes available to those minerals. Also, recycling can aso help to alleviate the vunerability. (Althaf & Babbitt, 2021)

New Electronics have many elements, that orginate from more than 50 countries. Usually there are more than 60 elements, which makes the todays electronic products difficult to produce and procure. This also means that the list of new additions to critical components list in electronics production is growing. (Hagelüken & Corti, 2010) U.S Department of Energy critical mineral list, U.S DOE critical minerals list and European Union Critical Raw Materials list contain minerals, such as cobalt and also rare earth elements (REEs) such as neodymium, dysprosium and europium, used in electonic displays, which are essential to produce modern technology. This growing list includes components with high and rising risk of supply chain distruptions. (Althaf & Babbitt, 2021) Therefore it is important to have alternative, diversified supply chains, cosidering possibilities of product reuse and application of cheaper, lower risk substitutes without making great environmental harm. At the same time, material sourcing cannot be dependent only on few countries in case of future crisis. (Althaf & Babbitt, 2021).

USGS (The United States Geological Survey) website study declared that critical minerals are essential to U.S security and economy, but the refining of those minerals has been declining decades and production is being concentrated in fewer countries, causing supply risk. USGS has started using artificial intelligence to collect info from 100000 geological maps, in order to plan usage of the land and speed-up collecting information for each mineral to start mitigating risks. (USGS, 2022)

Material supply chains need to become resilient to the border clousures, and alternative parts cannot be sourced from the same region. Different risks such as supply, demand, sociopolitical, geographical and environmental need to be mapped to understand the vunreability of the chains and critical minerals used in Electronics production better. (Althaf & Babbitt, 2021) To understand the risks and assess criticality of a mineral, it is important to know which factors contrubute to the risks. Some of the factors to conisider

are global reserves, mass percentage of material content in ore deposits, where lower concentration shows scarcity and more energy extracting cost for of the material, also static index of depletion, which shows how many years material can be used at current rates before the depletion, metal indexes which show price fluctuations, and as well as byproduct productionh percentage, which shows if the material is obtained as a byproduct, which makes it more vunreable. Also, annual mine production, which shows global production of a material. Consumption by Electronics sector, price, price indexes and price volatility also need to be considered. (Althaf & Babbitt, 2021)

In addition, labour rights, health and safety rules and infrastructure must be considered when assessing the risks. Since responsible and ethical production is becoming more prioritized in todays world, companies who violate human rights risk losing their profits one this is discovered. (Althaf & Babbitt, 2021)
Metals with highest usage in electronics Industry, for example on printed cricuit boards, can be seen in table below.

Category	Materials
Base Metals	Aluminium (Al), Copper (Cu), Magnesium (Mg), Iron (Fe), Ni (Nickel), Zn (Zinc), Ti (Titanium)
Precious metals	Au (Gold), Ag (Silver), Pd (Palladium), Pt (Platinum), Rh (Rhodium)
Technology metals	Sb (Antimony), Ba (Barium), Co (Cobalt), Ga (Gallium), Gr (Graphite), In (Indium), Li (Lithium), Mn (Manganese), Ta (Tantalum), Te (Tellurium), Sn (Tin), V (Vanadium)
Rare earth elements	La (Lanthanum), Ce (Cerium), Pr (Praseodymium), Nd (Neodymium), Eu (Europium), Sm (Samarium), Gd (Gadolinium), Y (Yttrium), Tb (Terbium), Dy (Dysprosium)
Hazardous metals	Pb (Lead), Hg (Mercury), Cr (Chromium), Cd (Cadmium)

Table 1. Materials studied. Modified by the author. (Althaf & Babbitt, 2021)

Risk mitigation can be done in electronics supply chain by supply chain diversification, stockpilling, recycling, material substitution and regulatory changes. This kind of change can be for example mineral tax implementation. In the past, during 2010 REE (rare earth element) crisis, supply chain resilience was kept mainly through substitution of 10% of the total demand with alternative materials and decreasing market concentration for non-Chinese production at a speed of 4% per year as can be seen from graph showing herfindahl-hirschmann index below. Therefore, companies started to use non-Chinese primary production sourcing and substitution as main ways to mitigate the risks associated to the crisis. Sadly, recycling was used minimally as a solution to alleviate the risk. Recovery from the 2010 distruprion took two years, therefore a longer period of material constraints is needed to pressure manufacturers naturally into recycling. (Sprecher, et al., 2017)

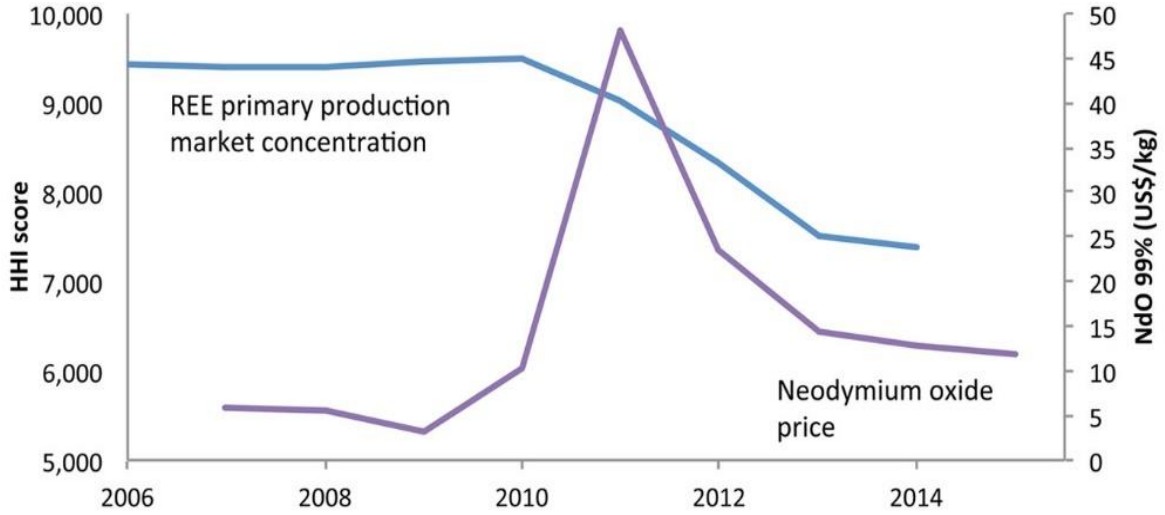


Table 2. REE market concentration. Not modified by the author. (Sprecher, et al., 2017)

REE-s have the highest risk of supply chain geographical production concentration. Most of which, are also high risk in terms of Electronics sector consumption, ore concentration and risk of global reserves as these are the metals that have the highest usage in electronics production but are very globally concentrated and difficult to mine due to their ore concentration level. Many of the REEs are also produced as a byproduct during production process (Pr, Nd, Eu, Sm, Gd, Tb, Ey). Luckily the REEs are not high risk for culmulative energy demand, global warming, depletion (as a nonrenewable resource) and material resource demand. (Althaf & Babbitt, 2021)

Highest risk for Electronics production from technology materials are Ga, In, which are critical in terms of global reserves and ore concentration. Second in risk are Co and Li. Third are Ta, which is also critical in terms of global reserves and Sn. (Althaf & Babbitt, 2021)

Out of all minerals, for which electronics consumption risk effect is not high, the most critical in terms of global reserves are precious metals (Au, Ag, Pt, Pd, Rh). Out of technology metals, most affected are Ga, In, Ta, Te. (Althaf & Babbitt, 2021)

Materials group	**Risk of global reserves**	**Risk of ore concentration**	**Risk of Electronics sector consumption**	**Risk of Geographical concentration**
Precious metals	High for all	High for all	Low for all	Medium for all
Technology metals	High for 33% (Ga,In,Ta,Te)	High for 25% (Ga,In,Te)	High for 50% (Co,Ca,In,Li,Ta,Sn)	High for Ga (8%)
REE-s	High for 60% (Eu, Sm, Gd, Y, Tb, Dy)	High for 70% (Eu, Sm, Gd, Y, Tb, Dy, Pr)	High for 80% (Eu, Sm, Gd, Y, Tb, Dy, Pr,Nd)	High for all

Table 3. High risk materials in electronics production. Modified by the author. (Althaf & Babbitt, 2021).

The study concludes that highest risk materials for electronics production and supply chain distruptions are rare earth elements, also gallium, cobalt and indium are considered to be high-risk in terms of supply chain disruptions, because of the geographic concentration and production as a byproduct. Precious metals have high risk in terms of global reserves and and ore concentration, but they cannot be considered high risk in supply chain distruptions due to low usage and not being geographically concentrated.

Rare elements appear in very small concentrations and the process used to separate them from the rocks during mining is difficult. Furthermore, extraction process requires thousands of extraction and purification stages and because of that, their value is very sensitive in market and geopolitical effects. (Kirkpatrick, 2019) In addition, as their production is very concentrated, the distruptions will be immediate if the effects of disruptive event such as political decisions, production difficulties or a crisis will be happening in the producing region.

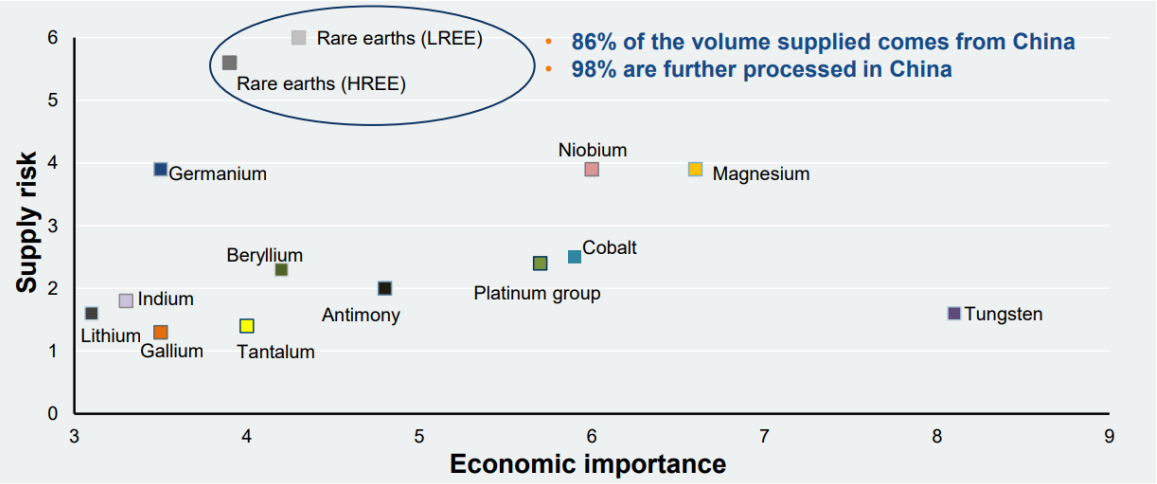
Since more than 75% of global electronics production is concentrated in 3 countries which are China, Hong Kong and the U.S. (Which Countries are Most Important in

Electronics?, 2022); (Althaf & Babbitt, 2021) and for more than 50% of materials, production is limited to one or two countries, mainy China being the main provider and China furthermore has an only increasing share in refinery capacity. (Gulley, McCullough, & Shedd, 2019)

If U.S. were to increase their REE production by 30% safter 2019, while China would not increase theirs, geopolitical and social distruptions risk would decrease by 16% and 35%. Supply diversification is key to decreasing distruptions caused by social and geopolitical reasons for REEs. (Althaf & Babbitt, 2021)

80% of the REE production has been concentrated in China. Although reserves exist more or less equally (around 15%-17%) in countries such as Brazil, Russia, Vietnam and also 6% India. While Australia has only 3% of the reserves, which is less than in any other mentioned country, they contribute 15% to annual REE global mine production. US has increased their REE production from zero to 30% in 3 years from 2017-2019, which is equal to 12% of global production, while during the same period, China's contribution to REE production declined to about 60% (USGS 2020). Recycling has the potential to reduce risks for distruptions up to 30%. (Althaf & Babbitt, 2021)

REEs have few substitutes in case of a disruption. For example, europium, which is a critical component used in light emitting diodes (LED) while Samarium is widely used as a permanent magnet for hard drives, audio speakers as well as motors. At the same time the recycling rates for REEs, indium and gallium are below one percent (Ciacci, Werner, Vassura, & Passarini, 2018)



Source: Study on the EU's list of critical raw materials (2020), final report

Table 4. REE criticality in electronics production. Not modified by the author. (ZVEI Electrifying Ideas, 2022)

2.2.1 Electronic components supply chain geographical situation

It is important to differentiate companies who are contract manufacturers and have their own manufacturing sites (foundries) and companies who do not own any production facilities and are called Fabless companies. The latter fous only on development of the semiconductors, such as NVIDIA, AMD/ATI, Qualcomm, main customer for those is TSMC Taiwan. Foundries are companies such as NXP (Netherlands), Texas Instruments (USA), Infineon (Germany), Renesas (Japan) and TSMC Taiwan with focus on signal and information data. Asian foundries are Samsung (Korea), UMC (Taiwan), SMIC (China), TowerJazz Panasonic Semiconductor (Japan), VIS (Taiwan), PSMC (Taiwan), Hua Hong (China) and DB HiTek (Korea). (Frieske & Stieler, 2022)

Although there is enough diversity of production companies around the world, experts predict that China will become an even stronger leading producer in terms of wafer supply by 2024. Wafer is a semiconductor base material mainly made of silicone. This will make the semiconductor supply chains even more vunerable to any disruptions coming from China. Expected growth in global wafer output is 5% of volume increase per year. (Frieske & Stieler, 2022) In terms of Europe and the US, it is important that the wafer supply would not rely solely on China as it is now, to be able to difersificate the wafer supply. This also enables the wafer leadtimes to shorten, current ones are around 3 years.

For example out of the 200 mm variants for wafers, approx. 5.6 million units, which makes a share of 20% is produced by China, followed by Taiwan (19%), South Korea and Japan (17%), the USA (11%) and Europe (8%). (Frieske & Stieler, 2022)
It can be clearly distinguished that Europe is highly dependent on Asian countries compared to other five regions. Mentioned six world regions represent 92% of global wafer production, which is approx. 28 million units per month. Europe has two largest microchip producers with global sales reach, and both of those are focused on automotive market (NXP, Infineon). As mentioned before, this market has the lowest negotiation position in terms of annual sales volumes, so it can be concluded that for increasing the revenue in the same tempo as Asian and US manufacturers, European producers need to expand their segments more aggressively to communications, data technology and consumer segments to stay competitive. For foundries manufacturers, production is running 24/7 in 3 shifts, so it is crucial to maintain the competitive positon. (Frieske & Stieler, 2022)

Latest research shows that China has developed into politically ambitious and economically strong world power. It is important to note that China's success is based on a different system of rights and values than Western industrialised countries, which are based on free world trade and access to other markets and activities, which contribute to improving the working and living conditions of citizens. Diversification of global supply and customer networks will be the main contribution to a reliable future and values, to avoid depending solely on China. This also means gaining more customer opportunities in the Asia-Pacific region. This requires coordination with the EU and a need or a unified industrial, foreign and trade policy towards China, which also should be coordinated with the USA. (ZVEI, 2022)
It needs to be considered that China is the most important market for the German electrical and digital industry. Opportunities related to China must be used, but the risks and challenges managed at the same time. To increase competitiveness of the EU, focus must be on strategic sovereignty, promotion expansion of technologies. European trade policy must grant greater access to other markets than China, which means more targered free trade agreements with the Global South, for example following countries: South Korea, Singapore, Vietnam and Indonesia. Also establishing a new EU-China trade policy is needed. ZVEI also states that the European Raw materials policy (Critical Raw Materials) must be geared in order to reduce unilateral dependencies on China as the currently 86% of the rare earth elements (REE-s) mined come from China and 98% are processed in China, alternative producers could be Canada, the USA, South America and Africa, but currently only few countries besides China are willing to extract and mine REE-s and process them, so they could be used in electronic industries. To promote European interest, raw material cooperation should be promoted with FTA-s, this can be ensured with EU punitive tariffs and investment programmes such as Global Gateway initiative. The EU single market should be viewed as a reliable asset for countries like China, and can be used to negotiate from the point of the EU perspective. China needs to be included in organisations such as WTO, so China would migrate to own organisations with own values only. (ZVEI, 2022)

In 22 years between 2000 and 2022, China has become the largest export customer and importer of the German electrical and digital industry. In 2021 as much as 32% electronic and electrotechnical product imports to Germany were made by China, whereas 11% of electronic and electrotechnical exports by Germany were made to China. (ZVEI, 2022)

China`s current share of global electrical and digital goods market is 43%, and it has grown by an average 13% each year starting from 2000. Europe has share of 16% and America 19%. In comparison, the world growth has been 3% annually. Also, Asia accounts for two-thirds of the market production. (ZVEI, 2022)

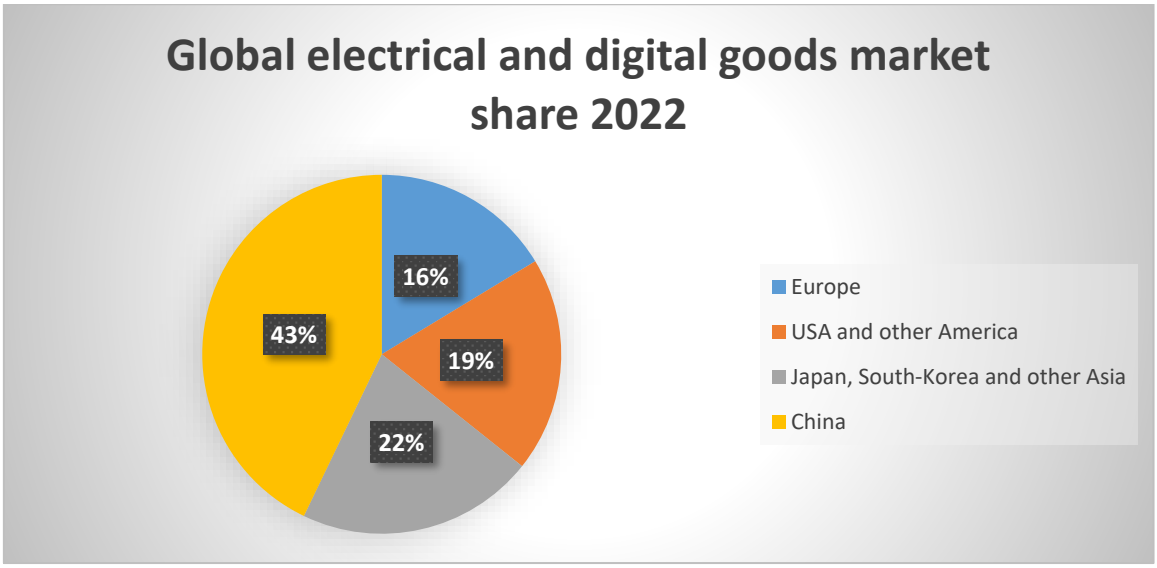


Table 5. Global electrical and digital goods market share. Modified by the Author. (ZVEI, 2022)

Also, for the first time in 2021 China is ahead of the EU in terms of global economic ouput.

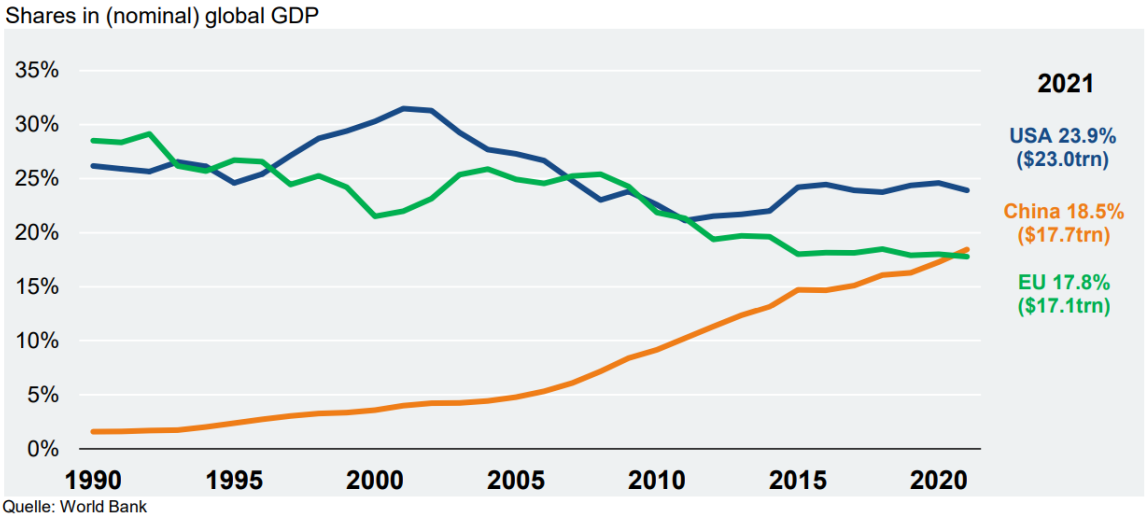


Table 6. Shares in nominal GDP. Not modified by the author. (ZVEI Electrifying Ideas, 2022)

Globally, in 2019, the US manufacturers dominated the market with global microchip sales market share of 51%, followed by South Korea (19%), Europe (10%), Japan (10%), Taiwan (6%) and China (5%). From 2001 to 2019, Japan has seen a decrease from 28% to 10%, while South Korea has increased the sale from 6% to 24% in 2018 (ZVEI. Entwicklung der Halbleiterindustrie, 2019). Additionally, China has a goal of CO2 neutrality in 2060, which may impact the current strong market position.

2.3 Current situation of the Estonian electronics sector

Estonian electronics sector was established in 1907 when the first phone factory was builded. Currently 12000 people work in the Estonian electronics Industry, and the industy is the most digitalised and automated industry in the country. We have around 250 active companies in the Estonian elecronics Industry. Also, 93% of the electronics producs manufactured are being exported to Sweden, Germany, Finland and the USA. (elektroonik.ee, 2022)

According to current trents Electronics production is moving back from China to other asian countries as well as to Europe and America, which means the estonian Electronics sector is benefiting from those developments. Nowadays is important that the end products reach the market fast, which is one of the reasons why mass production is brought closer to product development teams and the end customer. To be able to do that, estonian electronics sector is in currently in the need of new qualified workforce. Estonian Electronics sector is important part of the economy as it forms 25% of estonian Industry export. (elektroonik.ee, 2022)

Estonian electronics Industry association was born on 3rd of June 2010, being founded by ten estonian Electronics companies, with the purpose of elaborating partnership between electronics industry and educational instiutions and to help to maintain competitivness in the fast developing indusry. Being part of the associaion offes many collaboration opportunities such as sharing information about trustworthy suppliers, excess sock, difficult customer orders etc. (Estonian Electronics Industries Association, 2022)

Estonian electronics Industry companies have managed well in the component crisis. The chairman of estonian subsidary of the international electronics company InCap Otto

Pukk stated, that managing the crisis is part of the team leaders job and part of the successful leadership style and only those who adapt to changes survive. InCap has implemented a decentralised leadership style, where workers are allowed to make decisions on a local level as soon as issues arrise and this keeps them motivated. Their national headquarters has only 4 people in charge because of the decentralised leadership style, which is also cost-effective to the company. (Estonian Electronics Industries Association, 2022)

Also, the Electronics Industry association managing director Arno Kolk stated that during the recent years COVID-19, war in Ukraine, energy and transportation costs sudden increase has been challenging for the sector. Warehouse stock levels inceased because of the component crisis and production was planned according to warehouse stocks, not according to the demand of the customers. Companies have still made investments to automate and expand the production, as overall the demand is increasing because of the 5G networks which are being expanded across the world, digitalisation, developments in the medical sector and demand has started to grow in the automotive sector as well. (Estonian Electronics Industries Association, 2022)

CEO of Finesta, Heiki Mäki stated that the impact of the economical crisis expected by the spring of 2023 was smaller than expected, but nevertheless there is no sense of security in the sector. The future depens on many unpredictable events, such as how and when will the war in Ukraine end, how fast will inflation fall, and how will intrest rates react, which will be the impact of Chinese economy opening up after numerous lockdowns. He predicts that 2023 estonian industry situation will be as unpredictable as it was during previous years. He says that renewable energy sector is doing currently very well as russia has exited the market as an energy supplier. (Estonian Electronics Industries Association, 2022)

German company in4ma expert Dieter G. Weiss has stated that electronics Industry is currently facing many managerial and leadership challenges and the real problem is not the chip crisis but the behaviour of customers of the electronics Industry who have collected big warehouse buffers and panic-ordered, which means 20-30% of the new orders are being canceled while material prices have increased and payment terms are being extended. This means that the actual annual economical results are impacted, while it is common to assume it is related to the chip crisis. (Estonian Electronics Industries Association, 2022)

As a result of COVID-19 production will partialy be brought back to Europe from Asia finds study published by Estonian developmental studies centre. The study finds that for Estonia to be part of those investments, the country has to offer stable economical environment and involve foreign specialists to fill the gap. Also, pandemic has pushed digitalisation, automation and risk plan developmets in Estonia. (Arenguseire keskus, 2020)

This is especially important as electronics and electrical equipment production is a sector with very high export rates. Main indicators for growth of Electronics sector are Industry 4.0 and 5.0, the internet of things and environmentally friendly development goals, such as green energy. To make sure that customer demand is fulfilled and companies are able to deliver without facing critical supply errors, it is important to bring manufacturing closer to the final customer markets, the study finds. In the Estonian electronics industry there are mainly foreign owned companies. These companies make around 90% of the export of the sector. Foreign investors apprciate predictable and stabile economy and suitable workforce, which have attracted investments so far, but the key forward is development of specialists and smart industry. So far main blocking points during pandemic have been supply issues, restrictions of movement, trade wars and labour problems. In 2019 there was 2,3% of workforce occupied in Electronics and electrical equipment production, who generated 382 million euros worth of added value, and counted for more than 8% of the export. (Ärileht, 2020)

According to 2020 study, Estonian Electronics and electrical equipment sector was in 9th place out of 17 for crisis resilience. (Ärileht, 2020)

Also, European Comission has announced the European Chips Act, which is 43-billion-euro package of public and private investments to avoid shortages and secure supply chains of the semiconductors. Another aim is to develop and promote investment into the industry, foster digital and green transition as chips are strategic assets for electronic industries in the EU. Main goal is to strenghten technological leadership in the EU by increasing production capacity to 20% of the globaal market by 2030, innovate design, research, skilled workforce, new manufacturing facilities, ensure supply security and and manufacturing. In the world 1 trillion of microchips were manufactured in 2020, share of the EU was only 10% of those. Industry expects demand for chips to double by 2030. As semiconductor shortages are ongoing, this demand will be challenging to meet. (European Comission, 2022) Europe has shown drawbacks in chip development while being a leader in machinery manufacturing and auomobiles. German

Auomobile Industry Federation called the goverment to take action in solving chip supply crisis. (Xiling Wu et al., 2021)

Estonian electronics industry associaion conducted a mapping study in 2021 among 11 participants from Estonian eleconics industry, who were also membes of the industry, resulting in a study report. Mentioned companies annual sales in 2020 was 976,8 million euros. Those companies rated "high" (56%) or "average" (44%) to their state of current tecnological level. Priority field of development for all of those companies is IoT, mainly in the fields of energy systems, industrial communication equipment, automotive, medical and robotics fields. All companies were exporing worldwide, whereas 88,5% expected to see growth in new markets, products and company size. Stoppers for that were human resources and market demand decrease. 36% of responders said that coopertion inside Estonia has stoppers such as competitive environment due to local market size, corporative policies and caution, whereas 28% said the cooperation inside Estonia between companies and universities is good. All companies stated that bringing development centers to Estonia is neccessary. Companies also stated that the effects of the compnent crisis and labour shortage were bigger in 2020 than the direct effects of the COVID-19. It was predicted that compinent crisis will continue to 2023 and onwards, which has negative impact on the profits. (Estonian Electronics Industry Association, 2021)

2.3.1 Estonian electronics sector financial overview

Statistikaamet has published an overview of the electronics sector for years 2017-2021. This statistics is an useful tool to get an overview of the changes happened in COVID-19 years compared to earlier period.

It needs to be mentioned that assumptins based on financial data can be caused also by other effects than COVID-19 and related effects such as the global component crisis. The data gives an indicative of the trends in the industry and related changes.

Overall, the number of companies and amount of workforce has remained stable. Total productivity of the company based on turnover has not changed during the pandemic years.

Rapid growth in finished and unfinished product inventory can be seen in 2021 compard to the opening inventories in the beginning of the period, which is an indicative of the high stocks caused by stockpiling, which happened in 2019-2020. There is also a very clear inducation of assets increase in 2021, growing 16.85% in 2021 compared to 2020. This is an indicator of stockpiling started in 2019.

Labour costs have increased steadily up until 2021, which confirms that companies had to maintain specialised workforce, which is in overall shortage in the market. But during 2019-2021 the growth of labour costs has slowed down in 2020 and 2021 due to the unstable economical environment and stabilization of profit and revenue figures. Profit to revenu ratio has decreased year by year starting from 2020, which is an indicator of the increased costs.

The data indicates that total financial year losses for the companies who faced losses had increased significantly in 2021 compared to the previous four years, increasing by 79,9% in 2020 compared to 2019 and increased further in 2021.

Due to the unstable environment, immaterial and material investmens had slowed down significantly, fixed assets reduced by 53% in 2020 compared to 2019.

	2017	2018	2019	2020	2021
Number of companies	118	115	124	134	130
Average number of employees	5835	5961	5905	5768	5797
Sales, in thousands EUR	1 346 303,8	1 295 524,0	1 295 524,0	1 193 715,0	1 200 792,3
Finished and unfinished products inventory, in thousands EUR	8 929,7	12 937,2	-7 518,4	-3 976,8	12 549,1
Total costs, in thousands EUR	1 333 553,3	1 279 231,0	1 188 783,7	1 163 580,0	1 189 689,7
Labour costs, in thousands EUR	110 139,2	122 801,3	132 754,3	138 005,5	143 898,7
Financial year profit, in thousands EUR	32 373,7	37 448,8	40 673,8	38 020,8	38 222,3
Financial year loss, in thousands EUR	-1 242,7	-2 459,3	-1 649,3	-8 191,6	-12 220,9
Total productivity based on sales	1,02	1,02	1,03	1,02	1,02

Worth of the produced parts, thousands EUR	1 326 553,0	1 310 561,5	1 214 823,9	1 180 911,9	1 205 608,5
Investments to immaterial fixed assets, thousands EUR	2 321,3	2 600,7	4 216,9	3 264,4	2 870,6
Investments to fixed assets, thousands EUR	41 926,5	38 457,4	58 652,0	27 499,4	27 778,7
Financial year profit % to revenue	2,42	3,01	3,47	2,71	2,47
Return on assets (ROA)	5,83	6,04	6,21	4,53	3,79
Increase in assets, %	1,04	15,14	6,88	5,16	16,85

Table 7. Computers, electronics and optical equipment production financial statistics. Modified by the author. Source: Statistikaamet, 2021

2.4 Concept of the global semiconductor and chip crisis

The COVID-19 crisis together with the control measures made impact on integrated circuit companies. The effect of this impact is called the global chip crisis. Study conducted in 2021 shows that global shortage of chips and semiconductors will continue beyond 2022 and since there is lack of efficient cross-border collaboration, supply and industry chain for production is long, international prevention measures are lacking, there are several economic, geopolitical and trade restrictions whereas the overall demand is increasing in the automotive industry due to electrification and development of AI. Chip shortage is a bottleneck for developing those technologies. The situation can be alleviated by re-allocation of market resources and strenghtening the international cooperation. (Xiling Wu et al., 2021)

The first industry to suffer under chip shortage was automotive industry. Reason is that it accounted only for 12% of global chip production, wheras communication accounted for 33%, industrial 12%, computers 29% and consumer electronics for 13%.(Xiling Wu et al., 2021)

Personal isolation, flight and port restrictions were main factors that caused the production capacity decrease and plants reduced their production output as a result. For a while demands for automotive chips decreased, since theywere forced to produce less due to the reduced capacity. Since home office coditions requred consumer electronics, the chip manufacturers switched resources to consumer electronics as automotive chips had insufficient orders and production lines were reconfigured. As the demands began to rise, there were not enough chip manufacturers for automotive sector and chip manufacturers had started producing more profitable 12-inch chips instead of the old 8-inch wafers, which based on cost and configuration were still in high demand. So chip crisis is a structural shortage. According to American Semiconductor Industry Association demand dropped 32% in May compared to January of 2020 and increased above January levels in December. (Xiling Wu et al., 2021)

Also, chip manufacturing is a complex process, taking 6-9 months from trial production until sales supply. What is more, automotive chip supply chain is higly globalized, meaning that the processes of production are distributed in different factories around the world. (Xiling Wu et al., 2021)

2.4.1 Global semiconductor crisis theoretical overview

In the automotive industry, coronavirus had a significant impact on supply in the beginning of 2020, followed by a rapid growth in demand in the second half of 2020, which had biggest impact in microelectronic and semiconductor products. Supply bottlenecks persist to this day, and electronics industry is facing raw materials shortages especially for semiconductors. Short-term supply distractions are overlapped with long-term structural features causing shortages. Therefore, need for risk management, practical implications and new strategies are needed to stay competitive. (Frieske & Stieler, 2022)

In the first and second quarters of 2020 automotive production fell by 9,6%, which translates into around 7,7 million vehicles. This caused OEMs to reduce production capacity and push-out or cancel incoming electronic parts. In the third and fourth quarter the demand rose rapidly due to the higher sales of electrified vehicles and recovery of automotive market in China. By that time semiconductor manufacturers had shifted prioritization to IT and consumer electronics customers (smartphones, laptops). Therefore bottlenecks for the automotive industry occurred from fourth quarter of 2020, which is still ongoing as of 2022. In addition to the suppliers, all automotive electronics manufacturers have had to reduce, stop production or carry extra costs due to the lack of electronic components. (Frieske & Stieler, 2022)

The use of semiconductors in automotive industry and other electrical vehicles will increase due to the development of electromobility, autonomous driving, remote monitoring and control, as well as increased electronic applications for all sorts of electric vehicles. Therefore stability of the supply chain is key indicator of the success of the company, especially for European automotive automotive manufacturers. Strategic management of supply chain risks is therefore necessary to avoid line down risk in the short term and to be prepared for future unexpected distruptions. (Frieske & Stieler, 2022)

The study found that acute, short-term impacts, such as fire in Japan in October 2020 leading to chipmaker AKM shutting down plant in Japan, Nobeoka for a year, caused also significant impacts to the semiconductor crisis. For example, an arctic winter storm, which led to closure of NXP semiconductor, Samsung Technologies and Infineon technologies plants in the US state of Texas added a significant impact since production was stopped for 1,5 months. (NXP Website, 2021) Furthermore, in March 2021, semiconductor producer Renesas faced a fire in their plant in Naka, Japan, which led to shortage of the wafer components. (Frieske & Stieler, 2022)

Most recent impact author of this thesis can name as a result of daily sourcing and procurement related work in automotive industry in Estonia, is fire in China at Wuxi Welnew Microelectronics in January 2023, causing many producers such as Osram, Vishay, Infineon, Bosch to push out production plans and create approximate allocation plans for electronics, which are changing weekly. The Wuxi Welnew factory is a sub-tier supplier to multiple semiconductor manufacturers. The fire impacts commodities such as MOSFETs, RF small signal and LED drivers. This example illustrates how the impacts in China has global effect on the production, including Europe. (Astute Group, 2023)

Long-term impacts are related to the complex production process of the semiconductor chips as well as the current structure of semiconductor market and industry. Customers of the automotive industry represent only 11% of the total sales of semiconductor producers as of 2020, another 65% is represented by the sales to other segments such as communications and data technology, for example telecommunications, amounting to EUR 352 billion. (ZVEI. Entwicklung der Halbleiterindustrie, 2019) Therefore short-term increase for production capacities for automotive industry is not likely. China is currently the largest sales market for semiconductor electronic applications, total market share in 2020 was 35%. From the year 2000 until 2022, Europe and Japan have worldwide sales market share less than 10% for semiconductors. This demand includes mainly automotive industry applications (37% of sales in Europe and 28% in Japan in 2019). Segments like communication and data technologies dominate demand in the USA and China. In 2019 the USA had only 10% of automotive sales market share and China had 7%. The biggest segment in the USA is computers segment with share of 38% and in China the communications segment with the sales market share of 42%. (ZVEI. Entwicklung der Halbleiterindustrie, 2020)

It is also important to highlight that in 2020 the share of segments in semiconductor sales market in Europe were as follows:

	Europe	**World**
Communication	6,5%	33%
Industry electronics	26,5%	12,1%
Data technology	16%	31%
Automotive electronics	35%	10,6%
Consumer electronics	16%	13,3%
TOTAL	100%	100%

Table 8. Semiconductor sales market segments, modified by the Author (Frieske & Stieler, 2022)

Out of eight of the largest semiconductor manufuacturers only three are focused on automotive market.These are NXP, Infineon and Renesas, with respective sales shares of 44%, 42% and 48%. Texas instruments has only 20% of automotive sales, Qualcomm 4% and NVIDIA (6%) and AMD/ATI 1%, based on which it can be concluded that clearly thir primary focus is communications and consumer segments. This business switch is understandable, as those consumers buy in much higher volumes which translates to bigger profit margins. Taiwan TSMC, which is considered to be the largest chip manunfacturer in the world, has only 3% of automotive share. Negotiating position for automotive industry products is therefore lower compared to other segments. Based on 2019 annual reports, german automotove industry companie ssuch as Audi, BMW, Mercedes and VW, who develop automated and autonomous driving, rely on cooperation mainly with Texas Instruments and Qualcomm. NXP and Renesas are relied on only for signal processing and information data, whereas Reneasas is relied on only for power supply of vehicle control.

2.4.2 New technologies in microchip production

Micochip production is a complicated process. Wafer production takes the longest, under normal circumstances 3 months. (Frieske & Stieler, 2022) As of 2023, market is facing wafer supply crisis, which makes the leadtimes even longer, meaning that microchip producers need to have forecast at least 3 years in advance to be able to deliver products on time.

To get silicon as a raw material it needs to be separated under high temperature from the quartz rock via chemical reaction. During this reaction it is freed from iron, aluminium and phosporus. After structure has to be homogenized to be able to produce a single crystal, so it could be processed into wafer, so the circuit structures could be burned on them. Increase in wafer diameter allows bigger output alnd lower production costs, increase from 200mm to 300mm doubles the output. (Frieske & Stieler, 2022)

Semiconductor production takes 6-9 months, as can be seen from below drawing. Production process is complex as process parts are completed in diferent factories around the world. (Xiling Wu et al., 2021)

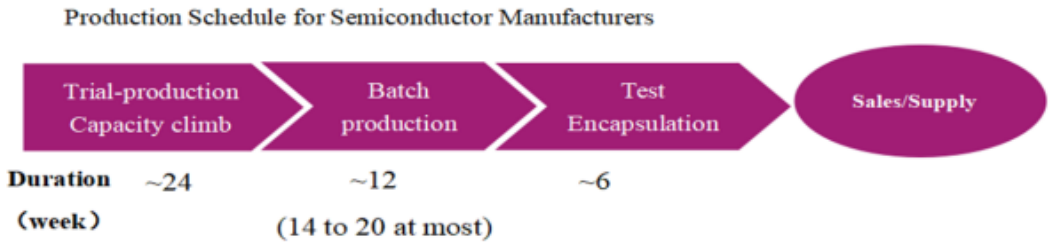


Table 9. Production Schedule for Semiconductor Manufacturers. Not modified by the author. (Xiling Wu et al., 2021)

The global chip shortage has had an revulutionary impact on research and development. These new technologies are in-memory-compute and neuromorphic chips. Many companies have decided to assign their wafer volume to the mature and risk-free high-volume products as it is important to consider high-volume product-type chips over research projects, but it is important to develop new technologies so semiconductor components leadtimes could shorten in the future and they would become more capable and accessible to alleviate the effects of current shortages. (Nature Communications Journal, 2022)

2.4.3 Technology war in microchip industry

„Technology war" means high competition among companies and countries who are leaders in developoing the microchip technologies. The field can be described as highly competitive and rapidly evolving. Main competitors to create more advanced technologies are China and the U.S with focus on developing smaller, faster and more power efficient microchips, striving to create chips measured in nanometers. In recent years China has invested billions of dollars in robotics, artificial intelligence, microlectronics and green energy. To maintain competitive position, U.S. companies have boosted investments in research and development, eased visa restrictions, patents and supported development of domestic talent, as well as undertaken government action. One of the examples, where microchips are used is 5G wireless infrastructure. (Darby, 2021)

China as a country has evolved to the extent, where it is currently improving the technology and also taking the lead on technological advancement in a similar impact with the U.S. This has been as a result of the continious technological focus of the state and massive investments development. As an example, the global technology spending has increased from under 5% to over 23% in 2020. Looking at current trends and assuming they will continue, China is expected to exceed United States in global technology spending by 2025. For example, the Chinese company Huawei has emerged as a world leader in 5G technology, being able to sell products at lower price than Finnish and South-Korean competitors. The company has gained a lot of state support, in the amount of 75 billion USD in tax breaks, grants, loans and land discounts. Chinese researchers currently publish more papers on artificial intelligence than American ones do, because of funding and access to enormous amounts of data. Chinese companies work closely with the state, and industry. Also the private sector and the defence industry are cooperating as a resuly of the military-civil strategy of the state. (Darby, 2021)

The U.S. government will need to fund research to help it make it to the market and commercialize academic research, develop public-private research facilities where the industry, academy and the government will be working together and sharing data. One of the great examples is establishing network called Manufacturing USA, to conduct research on manufacturing technologies. A similar initiative for microelectronics has also been proposed. (Darby, 2021)

In conclusion, continuous investments to the research and development as well as government direct impact on uniting the industry, academy and the government are important. These decisions shape the future of countries and impact who will be

dominating the technological advancement and own important technological systems and data.

2.4.4 Future predictions and challenges

The german research company In4ma states that the current and future macroeconomic problems in the electronics industry are labour shortage, rising energy prices and dependency on Chinese suppliers. Also, rising problem is the effect of the climate crisis. (in4ma, 2022)

Microeconomic problems involve stockpiling, current EMS companies in Europe should tärget to cut inventory by more than 60%, as well as make investments in digitalisation and clever automation. (in4ma, 2022)

Due to the high inventory levels, prices are expeced to drop and leadtimes to shorten, but this is not the case for all electronic components. For the duture green technologies and electical vehicles for automotive, will create a new increasing demand. Many countries and automakers have made the promise to be fully electric by 2040.

	2022	2023	2024
Revenue	599.6	532.2	630.9
Growth (%)	0.2	-11.2	18.5

Table 11. Smiconductor revenue forecast, worldwide 2022-2024. Billions of U.S. Dollars. (Gartner, 2023)

Already now, the cost of semiconductor products in premium vehicle is around 2500 EUR, but it is expected to rise to 5900 by 2025 because of the increase of autonomous driving functions, hybrids and battery-electric vehicles. (Infineon Technologies AG Website, 2020)

2.5 Component sourcing strategies in electronics supply

Component sourcing strategies and risk mitigation plans should be improved after every crisis. The electronic component crisis tested manufacturers existing processes and highlighted those companies and supply chain participants, who had not prepared for such risk occurrances.
As risk mitigation plans impact the financial health of the company strongly, it is something that needs more attention than ever before as the supply crisis is assumed to continue in 2023 and onwards. (Vatsfeldt, 2022) (Elektroniknet, 2020)

Price in some cases is not most important anymore, when it comes to production stops, continious production is more important, therefor delivery accurcy and short leadtimes are more important for continious delivery. (Vatsfeldt, 2022)

Also, imput from product development and vice versa should be considered when slecting new components for the BOM. Product development should be standardised, have many use cases and be as flexible as possible already from the beginning. Not being able to deliver creates unneccessary extra costs for the company, reducing profit, creditability and supply chain resilience, (Ivanov, 2020)

2.5.1 New ways of risk mitigation strategies

As we can see that due to new technologies demand for electronic components per product increases, manufacturing companies need to be ready for risk management strategies and processes.

Risk in supply chain can be dividend to operational risks like lead time and demand fluctuations and disruption risks, which are events with low frequency and high imapact. (Hosseini et al. 2019) Supply risks cused by epidemic can be categorized as a special disruption risk with characteristics such as long term, high uncertanty and ripple effects propagation. (Ivanov, 2020)

Below graph shows how supply chain resilience and robustness are direcly related to four processes: risk identification, risk assessment, risk mitigation and risk control. Risk control involves kowledge abou how risk management processes are designed.

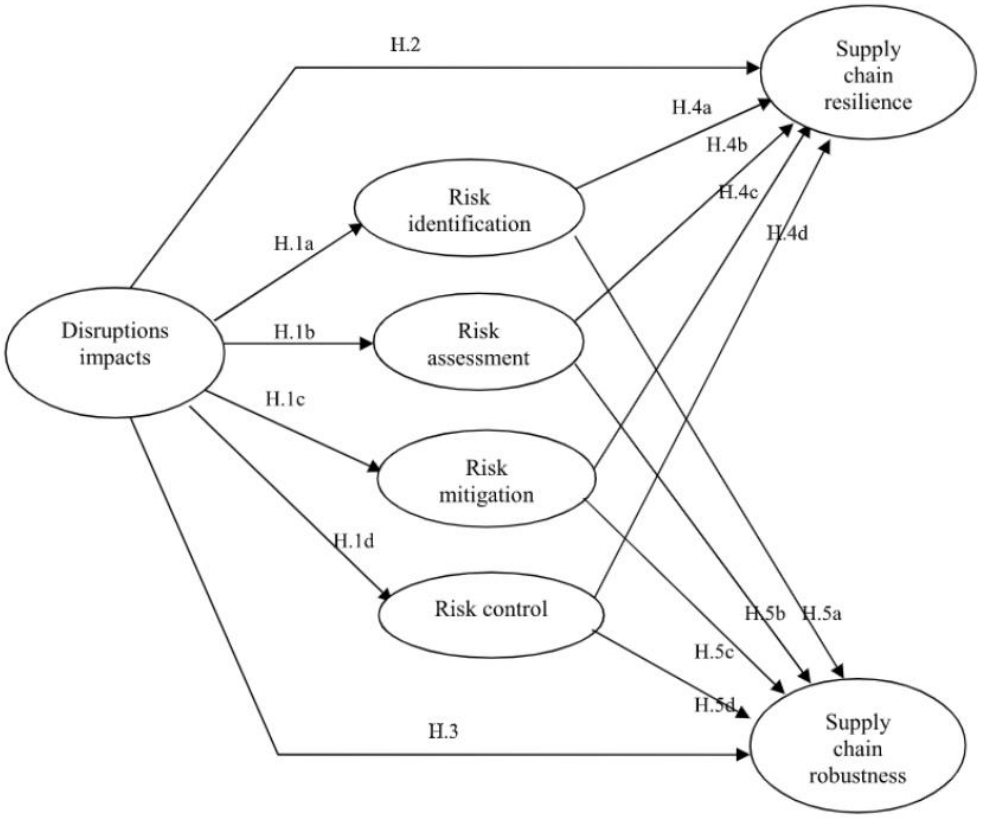


Table 12. SCRM matrix (Baz & Ruel, 2021)

A 2021 sudy conduced among 470 Fench companies, out of which 215 were in the manufacturing sector, assesed how the crisis impacted the firm's overall efficiency of operations, delivery reliability to customers and procurement costs of supplies. The study found that proactively maintaining SCRM (supply chain risk management) practices, firms can mitigate SC disruptions and in that way succeed in maintaining their planned SC performance. Maintaining performance is called supply chain robustness and recovering performance after having absorbed the disruption effects is called supply chain resilience. Study found that among studied companies, disturbaces affected SC robustness but not SC resilience as most of the companies stated that they will be able to recover their previous SC perfomance level. Although, to be able ro recover SC resilience, it needs significant adaptions by firms. The study found that risk identification, risk assessment, risk mitigation and risk control all effected supply chain resilience, while only SC risk identification and SC risk control have direct effects on SC robustness. SC risk identification impacted SC resilience and SC robustness the most. The way SC risk is identified has a direct impact on which scale companies control, assess and mitigate risks. The larger the firm, the more it has ability to initiate SCRM

planning and to use resources and processes compared to smaller manufacturers with inability to do so, leaving them more harmful to SC disruptions. (Baz & Ruel, 2021) SCRM is seen as efficient tool when faced with high-frequency-low-impact events, but wronlgly not if faced with low-frequency-high-impact events such as covid-19 outbreak. (Ambulkar et al., 2015)

„Supplier-manufacturer-customer" network is a base for strong supply chain and effective supply management system together with processes enables optimization of product, information and cash flows. To add more value, the network should be as visible and end-to-end as possible, meaning that it is not just the manufacturer, tier 1 supplier and the end customer, rather than all tier suppliers together with the raw manufacturer. (Gabler Wirtschaftslexikon, 2023)

This is especially important because the "supplier pyramide" in electronics industry is always complex. For example, in the automotive industry manufacturers are at the top, followed by development service providers, contract manufacturers, as well as just-in-sequence and just-in-time suppliers, and finally also logistics service providers with their partners. At the lowest level only highly standardized parts are manufactured. Each tier supplier adds components to the final module, followed by tests and quality control until it can be sent to the car manufacturer. Financial health and stability of a manufacturing company depends on all parties, therefore close interaction between OEMs and suppliers is part of the product innovation, supply chain and quality strategy. (Muchna, Brandenburg et al., 2018)

In the past, supplier relationships were defined only by the manufacturing cost of an item, if it was cheaper to outsource, it was purchased at a lower cost compared to manufacturing in house. Nowadays, suppliers need to be audied and certified while their processes and risk strategies reviewed, because the risks associated with supply chain dependencies between companies are high. (Muchna, Brandenburg et al., 2018)

During the electronic component crisis many of the companies have had to face production stops and send their workforce to short-time work or have had to lay off staff due to the long-term shortage of components. For example Audi sent staff to short-time work due to the shortage of electronic components at the Ingolstadt and Neckarsulm plants, which produce Audi A4 and A5. These examples are a good justification why a company needs to have risk mitigation plans and processes in place in order to reduce the impact. Supply bottlenecks will reduce profits significantly. Volkswagen could produce 100,000 fewer vehicles in the first quarter of 2021 because of the

semiconductor bottlenecks**,** which caused a drastic reduction in production. (Automobil-Produktion, 2021)
In 2021 approximately 9.7 million fewer vehicles were produced worldwide. (Lim, Zhao, & Torie, 2021) Worth of these is approximately EUR 223,8 billion, as consultancy Alix partners estimated to have significantly smaller, 3.9 million car production drop for 2021 which would have been worth 90 billion in 2021. (Alix Partners, 2021) Supply shortage will continue in 2022 and 2023. (Elektroniknet, 2020)

Some of the risk mitigation strategies are: use of temporary workforce and part-time work to meet the changing demand, updating production processes, adjusting inventories, emergency team implementation, alternative suppliers.

The study made by Frieske & Stieler in 2022 highlighted, that the german manufacturing companies interviewed found that it is most important to:

- make adjustments to inventories for the most critical products like specific electronic parts and cable harnesses.
- Establish a clear reliability and predictability of orders and requirements
- Define most important customer requirements
- Adjust and adapt to digital technologies (e-SCM) to exchange information and monitor the flow of goods
- Blockchain technology
- Dual sourcing and flexible shares
- Support local supply chains in Europe
- Support future supply chains of North African countries
- Monitor reliability of political action

In 2022 Madli Vatsfeldt conducted a master thesis called „The Impact of covid-19 pandemic challenges on supply planning process in ABB OY". Interviews were conducted with ABB OY purchasing manager Kimmo Lampinen who is responsible for purchasing activities in Estonia and Finland and procurement manager Mika Valkama. (Vatsfeldt, 2022)
From the first interview with purchasing manager Kimmo Lampinen it can be concluded that ABB was successful in maintaining the production and material flow during covid-19 pandemic and resulting electronic component crisis, as their customer were very satisfied with deliveries compared to competitors according to ABB sales department info. (Vatsfeldt, 2022)

He highlighted that ABB had already before the crisis established a team for risk management planning, who check critical market indicators of demand and supply imbalance, so ABB could react as early as possible. He suggested that firstly, a manufacturing company should define inventory levels they need to keep and also define the key critical components. A study conducted in 2020 found that only 57% of respondents out of 450 interviewed companies had identified critical supplies and suppliers to cope with the crisis and only 49% had business continuity plans. (Prasad, 2020) ABB keeps enough buffers at factory and supplier`s site. Defining inventory levels can be tricky, because during the crisis companies started panic-buying and stockpiling which later caused pushing-out and cancellation of the orders. (Vatsfeldt, 2022)

One of the offered solutions to mitigate those risks is implementation of e-SCM, which is an electronic supply chain management system. During the supply crisis manufacturers need more accurate and on-time visibility on component availability, incomings and shipments. E-SCM is a form of IIOS (Internet-based interorganizational system). In a study, in which data was gathered from 283 managers, of which 156 had adopted the system. (Lin, 2014)

Technological capabilities of the company were one of the major influences in adopting the system, although did not determine the extent of usage of it. Usage of e-SCM increased communication, coordination and collaboration between across organizational boundaries, which is crucial especially in times of very fluctuating supply situations, for risk mitigation purposes and for increasing competitivness. (Liu et al., 2010) Earlier forms of IIOS, like EDI, are slowly becoming outdated, as e-SCM is based on socio-technical interactions such as shared database and therefore enables joint decision making, exchange capabilities and business process integration. This also enables lower costs and more useful content for the parties. (Ke et al., 2009) (Rai, Patnayakuni, & Seth, 2006) Short term goals of e-SCM are to reduce cycle time and inventory levels, long-term goals are to improve end-to end processes of interactring companies, their customers and suppliers. (Rai, Patnayakuni, & Seth, 2006) (Narasimhan, Kim, & Tan, 2006) (Yao, Palmer, & Dresner, 2007)

The study found that implementation of e-SCM is now a top concern for top-level managers as it is proven to increase competitive position as a core competence of organizations. Major reasons for not implementing the e-SCM systems are technological challenges, internet technologies, expensive investments in hardware and software and employee training. Administrative, implementation, maintenance, setup, operating and training costs all inhibit technology adaption. Firms are concerned that invested cost will

not bring the expected benefits and lack knowledge in implementation of e-SCM. (Lin, 2014)
Secondly, a progressive and innovation-minded organizational culture is needed so the employees would adapt quickly to changes. New technology investment effectiveness heavily relies on how much time is invested in learning and training the employees and how committed is the management. This means that adopting new system means organizational change as well as updating the current business processes, therefore it involves organization as a whole. (Walker & Jones, 2012) Finally, another callange is that close collaboration between carriers, suppliers and customers is needed, therefore long-term mutual trust, good communication and relationships are essential to adopting e-SCM. Adoption decision of e-SCM is made based on cost and amount of useful functionality of the system. (Buxmann et al., 2004)

TOE framework can be used in order to define readiness to adopt e-SCM systems in a firm. It is necessary to look at technological, organizational and environmental context. Technological context describes firms technological capabilities and readiness, organizational context means characteristics such as firm size, number of employees, managerial structure, field of activity, turnover, quality and amount of human resources. Environmental context means industy specifics, government and trading partners. (Lin, 2014) Another, six-factor TOE analysis includes perceived benefits, costs, firm size, management support, information sharing culture and influence of the business partners. (Teo et. al., 2009)

E-SCM involves functions, that enable to trade with wider amount of business partners and have bigger possibility to compete in broader market segments. Also, competitive pressure drives search for technological competitive advantages, few examples are cloud-computing, EDI ans e-business. E-SCM will increase transactional and coordination efficiency between business partners. Based on the study, first companies in adapting e-SCM have proven to have biggest competitive advantages especially in higly competitive environments. (Lin, 2014)

Firms who implement e-SCM quickly had absorptive capabilities, significant firm size, saw perceived benefits over perceived costs, but implemented systems had to be significantly better than the existing ones, those firms also had supportive organizational culture (top management), and high competitive pressure. Also, it improved workers productivity and work efficiency. (Lin, 2014)

More resilient supply chains requirement leads to the need of developing IT tools and -systems to be able to make quicker data analysis and make the info flow more automatic. Current excel-based approach is becoming outdated. ABB is planning to develop information sharing via direct interface from suppliers ERP. In addition to that, ABB has established a systematic way to review KPI-s and supply status once a week, while visiting them once per quarter in person at their supply site. During the visits and audits process issues come up and ABB starts to support suppliers with those. Also, ABB expects clear priority information about what is critical on supplier side. Furthermore, suppliers have to have their own business continiuty plan. What is more, it is expected that suppliers share share capacity and plan production, while showing openly how material allocation decisions are made. (Vatsfeldt, 2022)

2.5.2 Updated risk management processes

Generators and renewable energy equipment producer ABB OY purchasing manager also highlited it is crucial to always have second source policy with at least two active sources. Although, it is important to know where the suppliers are ordering the material, if the last tier supplier is the same for both sources, the secound source policy will not help. (Vatsfeldt, 2022)
Additionally, as many as possible new alternative components and designs should be approved, so it would prevent a line-down situation in case of component sudden shortage. ABB sees that their risk management policy, for example risk mitigation documents in case of a fire accident of one of their their suppliers are in place. This is especially important for single source suppliers, as secound source policy cannot be implemented in every case, for example custom made parts. (Vatsfeldt, 2022)

Also, in the risk mitigation plan it is important to estimate how much time is needed to ramp up the new source. ABB wants to have an early warning in case of any supply issues to have enough time to react. This means creating visibility in the supply chain, updating risk plan frequently, creating global supply planner roles. People in these roles will develop processes full-time. (Vatsfeldt, 2022)

One of they key contributors to ABB-s sucess in crisis situation has been close collaboration with suppliers and also having proper KPI-s setup with the suppliers. They have a web survey, where suppliers are highlighting their disturbances. They aim to

have those questionnaires ro be sent out to tier-3 suppliers in the future. (Vatsfeldt, 2022) Risk management strategies should be applied to atles tier-1 and tier-2 suppliers, beyond tier-3 the risks should be undertstood. (Linton & Vakil, 2020)

Another key point is that the customer forecast has to be accurate. Some of the orders during the crisis came from panic ordering and often the forecast can be bigger than the actual orders. It is difficult to forecast non-standard products such as customer configured, make to order and engineer to order products. ABB OY purchasing manager estimated in 2022 it takes still few years to recover from the supply crisis started in 2020. (Vatsfeldt, 2022)

Direct high revenue risk impact in case of an supply disruption incident	Source from two suppliers 75%/25% based on cost, lower share to higher cost supplier	Developing alternative sources with sole-suppliers
	Map Tier-1 manufacturers warehouses, manufacturing sites, distribution sites for diversified regional approach	Ask suppliers to build and store parts at diferent sites
	Indentify Tier-2 suppliers building and storing locations that Tier-1 suppliers use for critical parts	Know where Tier-1 suppliers buid and store parts
	Buy Insurance to cover most of the lost profits during critical event	Buy insurance which does not cover most of lost profits during critical event for cost saving purpose
Indirect low revenue supply risk impact in case of an	Monitor suppliers 24/7 using artificial inteligence Monitor suppliers additionally for shifts	Monitor occasionally

supply disruption incident	that might increase their risk, such as a corporate restructuring, M&A, profit warning, lawsuits, etc in addition to	
	Know where suppliers' manufacturing and warehousing sites are located, and seek geographic diversity to avoid total loss of supply in future natural disasters.	Ask suppliers to build and store parts in multiple sites (particularly when an alternate supplier cannot be found)
	Identify suppliers that rely on the same sub-tier suppliers for critical materials	Ensure Tier 1 suppliers have comprehensive risk management programs (i.e., they map and monitor their suppliers, adding alternate sources for their highest-risk suppliers).
	Two or more sources qualified	Alternative source is available but needs to be qualified
	Low risk of supply disruption	**High risk of supply disruption**

Table 13. Sourcing risk matrix. Modified by the author. (Linton & Vakil, 2020)

This type of prevention measures cost, but when disruptions happen, companies are able to estimate within minutes how their supply chain will be impacted in the upcoming months. In that case companies will have knowledge in advance where the disruption will come from and which products will be impacted. Based on that info companies can start to offer discounts on substitute items, buy up existing inventory before competitors, book capacity at alternate sites or start to control some of the current inventory allocations between products. (Linton & Vakil, 2020)

2.5.3 Changes in inventory levels and planning

The component crisis caused stockpiling and panic-buying, where companies started to secure stocks multiple years in advance in order to avoid unexpected production stops and secure material in advance with the best

Already by the end of 2021, the stock levels in EMS Europe warehouses have reached extremely high values. The values were estimeted to be EUR 14.3 billion in 2021, which is around 33% of annual sales according to study by german industry reseacrch company in4ma. Surprisingly, stocks were significantly higher for the smaller EMS companies. In 2022 the stock value in Europe EMS warehouses reached 17.5 billion. (in4ma, 2022)

There is misconception that high inventory levels are positive due to rapidly increasing prices. It can be harmful for the company`s assets to keep stockpiling. In 2022 overall componenent prices started to stabilse and are expected to fall for certain categories in 2023. If the high warehouse stocks are booked at purchase price and they could be bought at a cheaper price from the market at a replacement value, then stocks must be written off to replacement value which causes decrease in assets. Distributors have implemented NCNR (non-cancellable, non-returnable) rules, to many of the components which makes returns often impossible. (in4ma, 2022)

The german electronics industry research company in4ma also states that the semiconductor crisis is not a real problem in general, the problem has been in procurement of specific types of chips (majority mature (40-450nm) and legacy (>450nm) products for Analog, MCU and DSP which are less than 8% of all semiconductors) for automotive industry. IC insights has published data about IC shipment growth, which indicates downturn of 6% from 2018 to 2019, after which IC industry increased output in 2020 by 8% and exceeded the 2018 input. Problem was that in the end of 2020, automotive industry wanted to ramp up production immediately due to increased demand, while JIT was not possible in the semiconductor industry. (in4ma, 2022)

When managing inventory levels it is also important to keep in mind if the parts are single sourced or not. Generators and renewable energy equipment producer ABB OY purchasing manager stated that keeping big safety stocks for the single source items is important to reduce risks. ABB is currently using lean principles in stock management,

which means they are selecting and defining high-risk items and keeping biggers stock levels for these. (Vatsfeldt, 2022)

According to ABB purchasing manager current supply chains are too dependent on China, therefore it is crucial to establish more sources in Europe and in North Africa in the future. Suppliers will need to locate closer tho the European factories. ABB procurement manager stated that it is dangerous to have all multiple sources in China. Moving production closer means also increased costs, but more resilient supply chain. (Vatsfeldt, 2022)

3. RESEARCH PLANNING

3.1 Methods of analysis

Focus group of this research is Estonian electronics sector. Methods of analysis are quantitative survey analysis and semi-structured expert interviews.

Regarding the first method, the aim is to get quantitative survey answers from the Estonian electronics manufacturing companies. In order to gather the answers, the survey is published in multiple channels. According to Estonian statistics publisher Statistikaamet, there were 130 companies in computers-, electronics- and optics production industry in 2021. (Statistikaamet, 2021) According to Estonian Electronics Industries association, they had 75 members in 2021, who covered most of the electronics sector industry according to sales numbers and value chains. (Estonian Electronics Association, 2021) The aim of the survey is to get an indication from the current sector situation.

First channel where the survey is published, is Estonian well-known industry news channel Tööstusuudised.ee, which belongs to Äripäev AS. (Tööstusuudised.ee, 2023) Second channel is newsletter of the Estonian Electronics Industry Association. Thirdly, questionnaire was distributed through business portal LinkedIn, targeted email communication and follow-up phone calls by the author.

Most of the questions in survey are based on 5 point Likert scale as it enables the items to be summed or averaged while giving input about positive or negative orientation of the responder. (Garcia, Araque et al., 2022) Survey was conducted in Google Forms survey application. There are also two open questions and two multiple choice questions. Survey questions are presented in appendix 1.

Additionally, the author will conduct three semi-structured qualitative interviews to get deeper understanding of impact of the component crisis on the Estonian electronics sector. Interviews will be held with three different sized companies. Full list of 17 questions can be found from appendix 2. Short conclusion of the topics is below.

1. Changes in production and material planning due to the component crisis and related extra costs to keep production running, accuracy of lean principles in today`s market climate

2. Changes in inventory levels and demand fluctuations, actual customer orders vs demand accuracy in today`s market climate

3. New ways of working, measurements taken to keep the on time delivery date, monitoring suppliers and cooperation.

4. Risk management activities such as multi-sourcing, alternative designs, region for region approach), sufficiency of previous risk management plans and measurements

5. Future predictions and recommendations

In conclusion the methods of analysis are qualitative semi-structured interviews and quantitative survey based on 5 point Likert scale, so the responders can clearly indicate their orientation towards the topics.

3.2 Aim and conducting of the research

The aim of the survey is to get an indication of Estonian electronics industries sector changes due to the impact of the component crisis. For the survey to give an indication, at least 25 responders would be needed as this covers 19,2% of the sector according to 2021 data. (Statistikaamet, 2021) Also, it is important that different sized companies would be represented, as according to Estonian Electronics Industry association 75 of those companies create most of the value chain and turnover, and thus, the larger the company, the more turnover it generates. Answers of the survey are anonymous since the survey questions contain business sensitive data. Answering the survey will take approximately 7 minutes.

Regarding the interview, it is important to distinguish different problems and changes companies with different sizes have faced. Survey gives a possibility to get in-depth

answers to complex topics related to the supply chains. Interviews give the responders also opportunity to add relevant topics or point out factors the survey will not cover. For the surveys to be relevant, at least three companies of different sizes are targeted. The responders of the interviews are anonymous to protect business sensitive data, but field of activity and position of the responder are published to give understanding and make in-depth analysis according to the field of activity. For the same purpose there is an open question in the end.

After the answers are gathered they are validated, analysed and categorised to be able to make clear conclusions. Interviewed companies will be marked with letters, Company A, Company B and company C. Results will be compared to the data and information gathered in the theoretical part.

4. RESULTS

4.1 Discussion of results of the interviews

Below is an overview of the field of activity and size of the three production companies interviewed. What is more, the description of the name of the position of the responder is given. As can be seen from the overview below, companies have diferent sizes and fields of activity.

	Company A	**Company B**	**Company C**
Field of activity	Telecom indusry	Electronics manufacturing services provider (EMS)	IoT software and hardware services company
Size	1800+	300+	160+
Turnover 2022	500M+	100M+	30M+
Position of the person interviewed	Category lead	Sourcing responsible	Sourcing manager

Table 14. Companies interviewed. Created by the author.

All of the companies were strongly impacted by the COVID-19 crisis and pointed out shortages.

For company A, the demands for their products had skyrocketed and they had to adapt quickly to the new situation, where demand was extremely high and was difficult to get the materials in. This caused big transportation extra costs. Regarding the electronics, the critical parts were shipped via express air transport. Company A had to adjust their production planning strategy and order critical compnents such as ICC-s up to to years in advance to be able to get the components. Since company A is a large global company, manufacturers prioritized their orders, so the main problems were freight

costs and planning production far ahead and placing orderd with extremely long leadtime such as two years.

For company B and C, the shortage also caused in production planning, purchasing, and filling customer orders. Unlike for company A, production for company B and C depended on one or few certain critical components availability and they did not know in advance what exactly we are able to produce and when, since manufacturers and distributors were not prioritizing them due to smaller volumes. So their production relied very heavily on material availability. Company C mentioned that their place in the market as a customer changed rapidly for the worse, as before they were able to get materials often in 6 months but now the arrivals for critical parts were unconfirmed and leadtimes extended up to two years for the critical parts.

Although, it was slightly easier for company B to get prioritization and allocation thanks to the additional escalations of their customers and larger volumes on certain products. Also, company B had few factories in Asia and Europe and distribution of materials and collaboration in terms of sharing best alternative market sources was very helpful.

Company C also mentioned that they had to significantly increase collaboration inside the company and with customers. They had as frequent as daily meetings with customers and internally, working with the most critical materials. Company B had weekly meetings internally and with customers. Company C also mentioned that they started to consider sourcing manager opinion already in NPI and early stages of BOM creation, to avoid difficult materials early on. As company B is an EMS, and they do not have their own product, they reviewed critical materials for the new BOM lists occasionally along the implementation process. Company B mentioned that their customers stepped in and supported more with escalations on critical level so all suppply chain up until to end customer was involved in handling the escalations.

The demand of company A had skyrocketed in 2021 and they had to pay a lot for it in terms of transportation fees. They had to fly in the materials frequently as the new normal. When the demand dropped a lot in 2022, when the war in Ukraine started and the economy froze. Previous high safety stock levels became a problem and inventory levels are super high in 2022 and as well as in 2023. Company A stated that some of the suppliers in electronics have still increased the prices by default to include some of the buffer fees because otherwise there is still no way to get them in time.

For company B and C it was not possible to make long-term production planning as before as purchasing opportunity for the missing components could have happened suddenly and they had to react fast. This caused the production plans to change often. Sourcing department work was more difficult and time consuming as they had to react quickly so they would not lose the cost-effective purchasing opportunity as many other companies were using the same tactic and buying stocks as soon as possible through various channels when they became avaiable.

Company C had similarily to comapny A also grown very fast in 2021 and was still growing rapidly in 2022. The current ERP that they were using did not satisfy our needs as they did not have a good visual overview, so they had to make additional excel files and found ways how to make better visual reports on what they were missing. They used Power BI for example to make data visually more easilly readable, so it can be concluded that the component crisis triggered implementation of new digitalization tools for e-SCM for better accessibility and easier readability of the increasingly growing and rapidly changing data. To discuss these tools internal workshops were made.

Company B added a leadtime KPI to measure accuracy of leadtimes and started to update the leadtimes at least once a month and also started to plan production according to the material availability as mentioned before. Currently this KPI is monotored in Excel, but company B also feels the need for higher degree of e-SCM digitalization. Company A already had a satisfying level of digitalization as they have had the resources, need and focus on digitalization before the crisis due to their size.

All companies stated that the inventory levels are very high and actions are being taken to reduce the inventories, such as selling stocks or selling existing products. The cashflow is stuck in high inventories. Company A mentioned that it is not easy to reduce prices as a yearly target as they have done previously and to reduce the stocks they have to lower the safety stock levels, while keeping them high only for critical items and single-sourced items foe which the second source is not possible. For some materials, they still need to pay the expedite fees. Since being able do deliver is not a focus anymore due to lower demand, the main focus is being profitable. This means that some positions have been made redundant, and to be profitable, then the second main goal is to digitalize and automate so that the positions made redundant could be replaced. Digitalization and automation has been always a focus, but it is more even now as a way to keep the costs low in the times of demand decrease.

All companies agreed that shortages have been bigger for microchips as a key component with extremely long leadtimes, allocations and alot of uncertain arrivals.

All companies agreed that lean methos are still vibale for electronics if you have a steady demand, but bigger stocks for critical and single-sourced items are needed. The key is to create more standardized products to be able to use the lean methods and to be more flexible in terms of inventory. Unlike company A, companies B and C had to make big extra costs in additional fees by purchasing materials with higher prices from open market and brokers as they did not get as high prioritization from distrubutors and manufacturers. High transportation fees were common for all companies. Company stated that if there is clear forecast it is easier to be lean, but they currently cannot follow reorder point as they order year in advance and then follow backlogs, so the crisis has pushed them for a faster new ERP system automation. The orders from their customers were not very accurate as well. Company B also stated that their forecast received from customers was not accurate.

Regarding the risk management, company A stated that they have a whole department dedicated to monitor the commodity prices and possible future risks. They even are using AI and automation so the company and suppliers could get an instant notification if any accident like earhquake or fire or a bigger risk like lockdown occurs. For example, copper prices rised suddenly in 2021 and suppliers forced to renegotiate the product prices immediately to continue producing, so such kind of events should be foreseen. Also, another risk management measure is product design change so it would have as much as use cases as possible. Another risk management measure was to allocate more people and resources to handle the critical commodities and create new tools to be monitor those faster. The general processes were redifined, but each person and each supplier defined those themselves, so it wasn't documented as an official process. Company A stated that although they had risk management plan, noone was prepared for covid and processes were still redefined. Company C and B had also not documented the new ways of working.

Regarding supplier locations, company A is aware of the direct supplier locations but not all tier suppliers. Info availability depends on if the product is designed by comapny A itself or not. The component crisis generated alot of extra workload. In terms of weaknesses, the company A stated that forecasting process from customers was not accurate so it was difficult to turn that into orders and to have the forecast accuracy towards our suppliers. Company C and B have also an overview of critical components, supplier locations and price changes, they are monitored frequently in

cooperation with distributors. Only customer had one distributor who had mapped our the whole microchip supply chain location. Company B also involved sourcing more in the NPI phase, but C clearly had a more in depth approach since they have their own product unlike EMS company B. Company B monitors market changes as well, for example metal index and approves more alternative components in designs.

Risk management steps for company C included adding more alternative components and improving product design. For them cooperation between product development and sourcing was crucial because due to the small company size some manufacturers were not cooperative and directed them to time consuming webshop applications, so they started leaving out certain manufacturers. Company C also noted that managing crisis was very time consuming, so they created methods such as integrating Power BI and Google sheets and brainstorming on new digtal tools to save time. Company C advantages were that they were small and got critical quantities from the open market, so it was easier compared to big automotive industries who had big shortages. And also due to the team being small, the teamwork was fast, quick and team was close, there were no corporate rules that would slow down the processes. So company C and B advantages were agility due to company A with clear corporate processes and rules, which can become overregulating.

For company C the role of sourcing is more important than before because the costs and difficulty of procurement has increased, so in the devlopment phase sourcing makes sure is possible to procure something within the expected leadtime and cost and checks alternatives availability, not only when the design is fixed. The engineers of company C suppliers also joined in to help, so this kind of cooperation is remarkable and more close than for company A or B.

Company A stated that the future depend on what will happen in terms of inflation, the war in Ukraine, economy and overall political and possible new crisis situation. Currently customers are holding back investments. Company C thought that together with green technology the demands will rise significantly after economy starts to rise again.

In terms of suppliers located in China, company A has been looking for alternatie suppliers. And also beacause of the political environment and the relations between US and China. For our US customers, having their suppliers located outside of China became become mandatory, so they have moved out a lot of items from China to to elsewhere or duplicated the factory locations, so suppliers would have multile locations.

Alternatives to Chinese suppliers have been Mexico and India. Company C has tried to procure more from Europe but the cost aspective has been the main stopper. In cooperation with distributors company C managed to find alternative cost effective sources in case their main distributors were not able to deliver.Company C and B had mapped out direct distributors and suppliers warehouses locations.

Following conclusions are made as final interview analysis suggestions:

1. Large corporative companies had alot of negotiating power in terms of getting the deliveries in, so for them main concern was express transportation costs, not additional multiple times higher prices for materials. Smaller customers lost their negotiating power in the market during the crisis.

2. The smaller the company, the more flexible, digitalised, adaptive and cooperative it has to be in NPI phase during product development as well as externally with customers because getting the materials in and being able to produce the selected design is a question of company survival.

3. Forecast accuracy and market unprectability was problem for all of the companies, this caused the panic-buying and stockpiling all companies are facing today.

4. Companies know first tier supplier locations, but generally not the whole supply chain locations.

5. Nobody was prepared for COVID-19 and for all companies new ways of working occurred. These now need to be defined into clear work processes to be able to form a risk management plan all companies currently are lacking.

6. Bigger companies are able to mitigate risks better by outsourcing supply sources to other regions except China as a demand from their customers since they have more room for the additional costs it brings. For smaller companies cost is main stopper for implementation. But all companies are moving in that direction.

7. Cooperation with suppliers and customers improved for all of the companies during the crisis as a measure for mitigation.

8. The crisis forced faster digitalisation and automation and usage of the AI of the e-SCM tools as a way to mitigate risks, costs, increased workload, increased data and to be able to visualise in a faster way and make decisions accordingly.

9. While crisis was growth periood for all of the companies, today they are focusing on being profitable instead of being able to deliver and that requires being cost effective.

10. All companies have implemented designs and alternatives to have as many use cases as possible as a way of risk mitigation and cost effectiveness. They are also avoiding sngle-sourcing and they have defined critical companents.

11. Lean methods are still valid, but critical components and single-sourced components need bigger safety stocks.

4.2 Discussion of results of the survey

The survey gathered 25 answers, which covers 19,2% of the companies in the sub-sector of computers, electronics and optical equipment production according to Statistikaamet. According to Estonian electronics industry association report, they had 75 active members, who covered most of Electronics sector turnover in 2021, which means that statistics according to statistikaamet may contain inactive companies. (Estonian electronics industry association report, 2021) Electrical equipment manufacturers are not considered, since they do not belong to the main focus group and there were no survey responders from electrical equipmnet production. The survey has a limitation of 25 responders.

The survey gives an indication of the changes happened during the component crisis as well as insight to future outlooks in the industry. 15 or 60% of the companies were older than 20 years, 5 companies were up to 15 years old and the rest 5 companies 16-20 years old. 11 responers had company size up to 99 people, 6 had 100-249 people, 4 had 250-499 and rest 4 of the companies the biggest size, over 1000 employees.

Firstly it is important to mention that 68% of responders (17 responders) have added alternative suppliers/manufacturers to Chinese ones. Reasons for not adding were no clear necessity (3 responders), not cost effective (2 responders) and 3 did not use Chinese suppliers in the first place.

All responders are monitoring the current market situation, 14 responders said that it is not directly related to anyone's work responsibilities, 11 said it was directly related to a specific person's or department tasks. It would be beneficial to add this as a task of a department or a person, since most do not have it directly assigned.

13 responders said that the forecast had differed significantly from real customer orders, 10 said it had differed slightly, 1 did not use forecast and for only 1 person forecast matched the orders. This highlights a clear problem with forecast accuracy.

Regarding the open question about materials, which caused biggest problems, variety of component categories were mentioned. Most problematic were microchips and also manufacturers such as Texas Instruments, Renesas, STM, OnSemi, NXP, Vishay, Infineon, Sumitomo, Intel, Xilinx, Altera, Diodes, Amphenol, TDK, ADI. Also mofsets, power transistors, dedicated IC-s, resistors, inductors, connectors, LED-s, electromechanics. Also industrial digital transformation and industrial automation companies were mentioned.

Regarding the open question about the effects of the crisis, main answers were that leadtimes were prolonged, extra costs were high and it affected the profits, workload increased, companies had to react fast and be adaptive, production plans were unclear until the last moment, availability of products to end customers decreased and the orders delayed. If the missing components finaly arrived it caused increased workload in production. Also, finding alternatives and approving them increased the workload. Also there were problems in warehousing, because the unfinished products took alot of room. In the beginning of the crisis companies paid extremely high prices to increase availability and also inceased the safety stock levels to high levels. Projects finished alot later than planned, which caused high extra costs. Also costs related to buying from brokers were mentioned. Alot of time was spent on developing alternative products with better availability. Possible loss of customers was also mentioned. For some of the responders, the crisis has been a time of record turnover. Main keywords were monetary loss, increased workload, delayed orders, increased inventories and big extra costs to brokers for materials, which usual suppliers could not deliver on time.

Regarding already implemented measures in supply chain, most popular answers were adding more alternatives, identifying critical components, improving cooperation with suppliers, adding suppliers from different regions and optimizing inventory stocks. It needs to be noted that cooperation with customers increased more than cooperation with suppliers. Those measures match well with theoretical risk management part instructions. It was suprising, that compared to measures brought out in theoretical part, supplier locations mapping, adding sourcing in product dvelopment phase and creating risk plans as well as standardiing product development were the least popular answers. Those who had mapped supply chains, had done it in detail, for the whole supply chain.

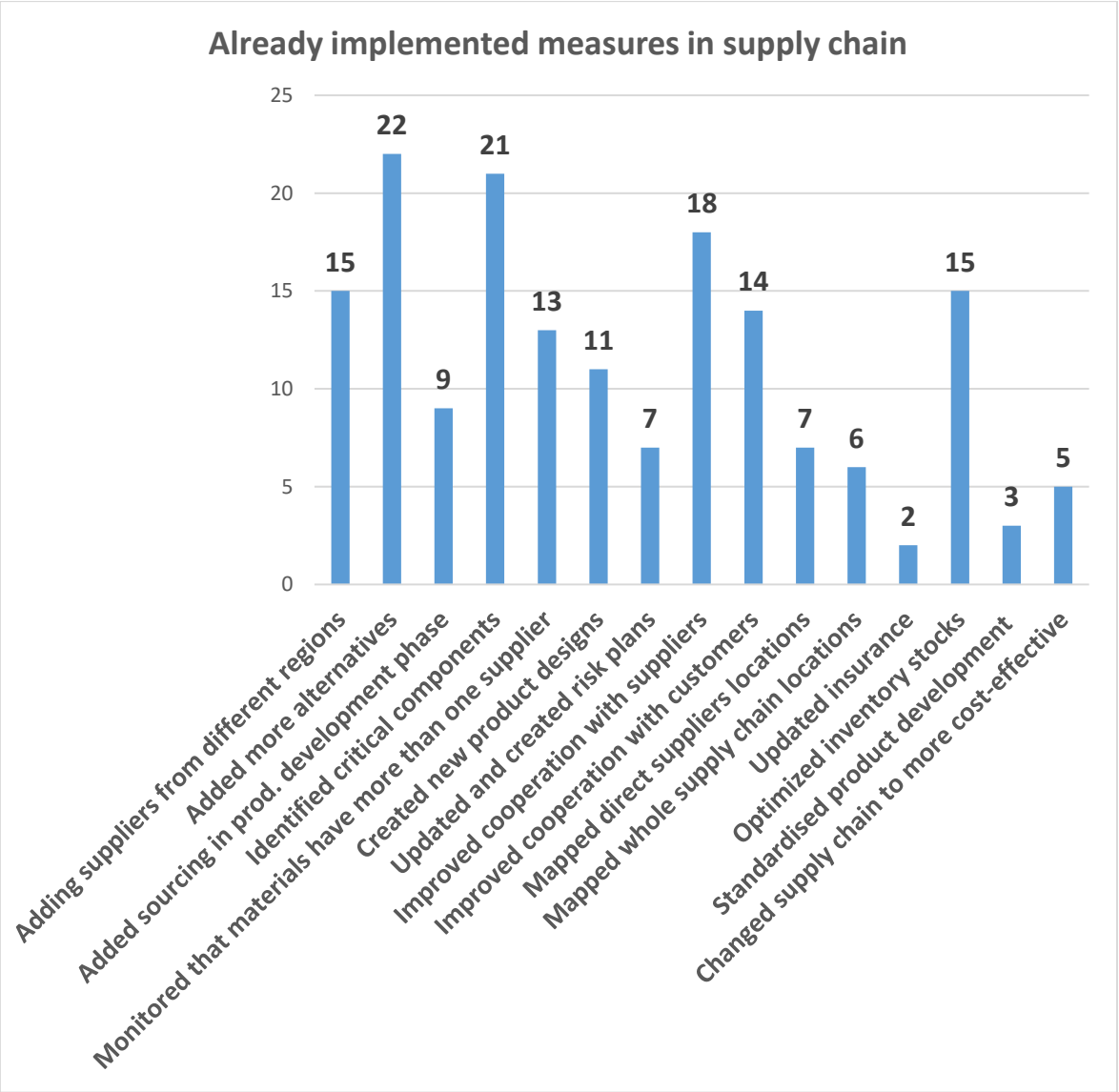


Table 15. Already implemented measures in supply chain. Developed by the author.

Regarding the most important improvements, in accordance with theoretical part, adding alternative suppliers, components, identifying critical components and optimizing supply chains were most populaar answers. The answers indicate that companies who have not added sourcing representative in product development phase would like to do so, around half of respoders believe it is important for the future. Although standardising product development was an unpopular answer for already implemented measures in supply chain, which was diferent result from the interviews. Also few companies thought this improvement is necessary, it should not be underestimated as a way to keep stocks low, moving and components accesible. Ordering from diferent regions was brought out by more than half of responders, who had also implemented those changes, this is also supported by the theory. More than half of the responders find that improving forecast accuracy is the key for supply chain resilience. In the questionnaire it was assumed that forecast accuracy improvement is not something that can be fully implemented yet due

to the lasting crisis situation uncertanty. This is one of the weakest points in building supply chain resilience. Supply chain digitalization was also an improvement that more than half of responders see as neccessary. According to theory it will help to save time, whereas component crisis caused more workload overall. It was suprising that risk plans and worker`s trainings were underrated, because new improvements and changes need to be documented and explained to workers, so they could be fully implemented.

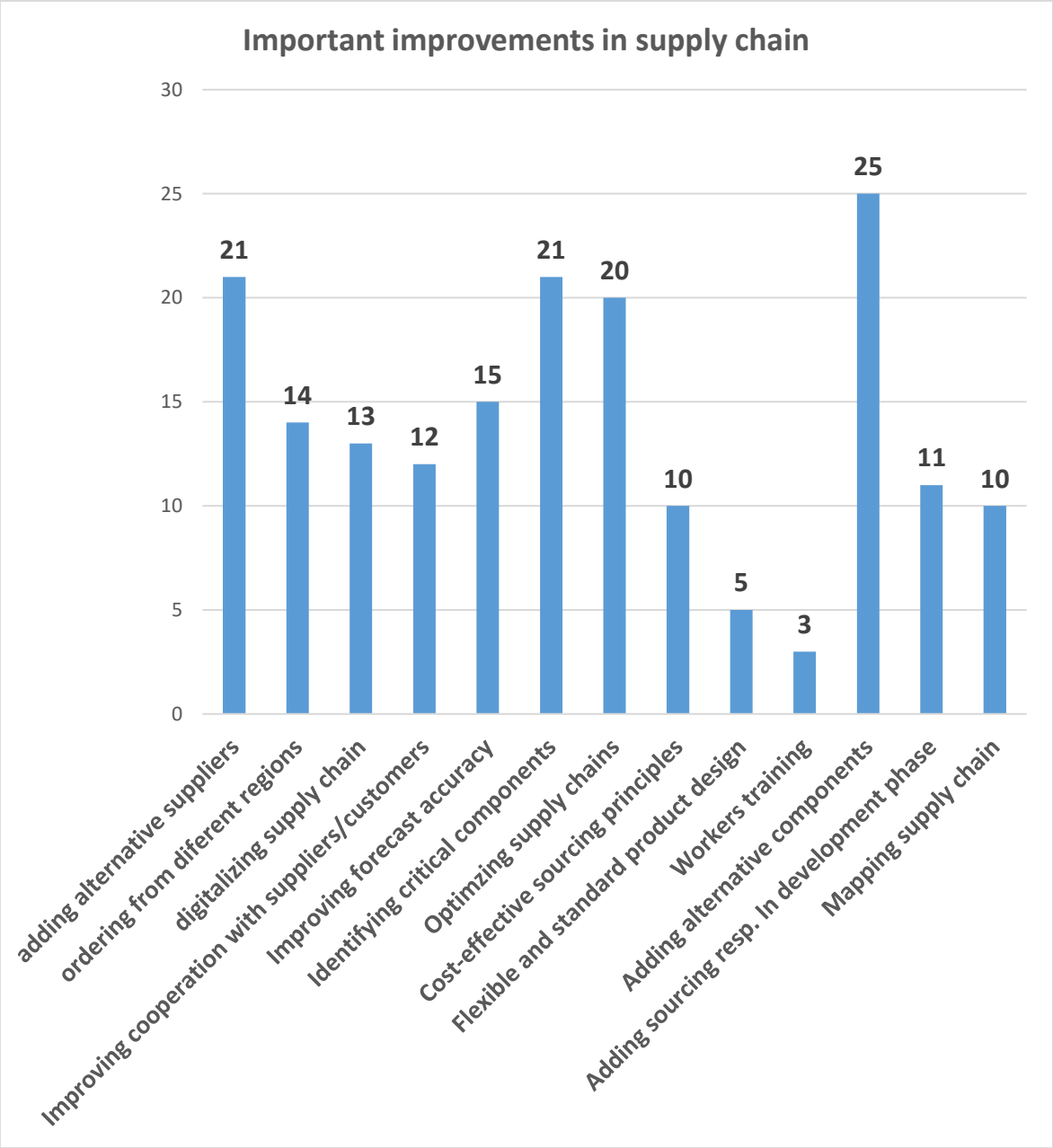


Table 16. Important improvements in supply chain. Developed by the author.

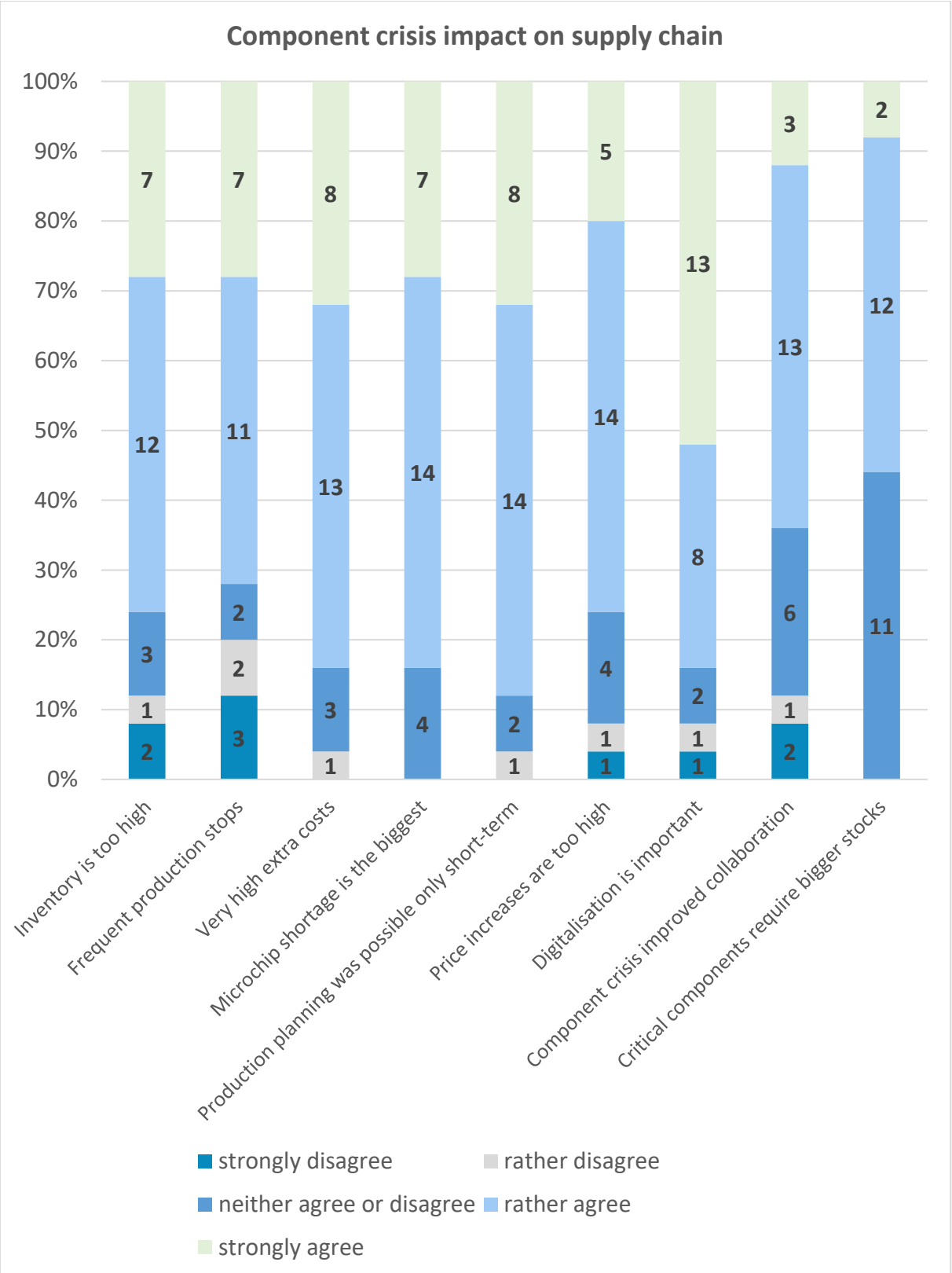


Table 17. Component crisis impact on Estonian electronics sector supply chain. Developed by the author.

Regarding the component crisis impact on supply chains, 19 of the responders (76%) believe that inventory is very high or high. This conclusion is also supported by theory.

Almost same amount experienced very frequent or frequent production stops. 21 responders out of 25 experienced high or very high extra costs. 21 out of 25 responders said they find microchip shortage biggest, although survey results revealed that problems occured with all kinds of componenents, not only microchips. 22 out of 25 responders found tht production planning changed to extremely short-term planning, changing last moment according to the few missing materials availability. 19 out of 25 found price increases high or very high. 21 responders found digitalisation as a key to reducing extra workload created by the component crisis and an effective tool to visualise data, reduce manual data reciving and entry and cooperate with partners. 16 responders found that the crisis brought companies closer and improved collaboration. 14 responders find that critical components require bigger stocks, but in the situation where companies are hesitant to increase stocks as warehouse levels are all time high, 11 companies neither agreed or disagreed. It can be concluded that overall for standard components lean principles work, but the critical lines need extra bigger safety stocks.

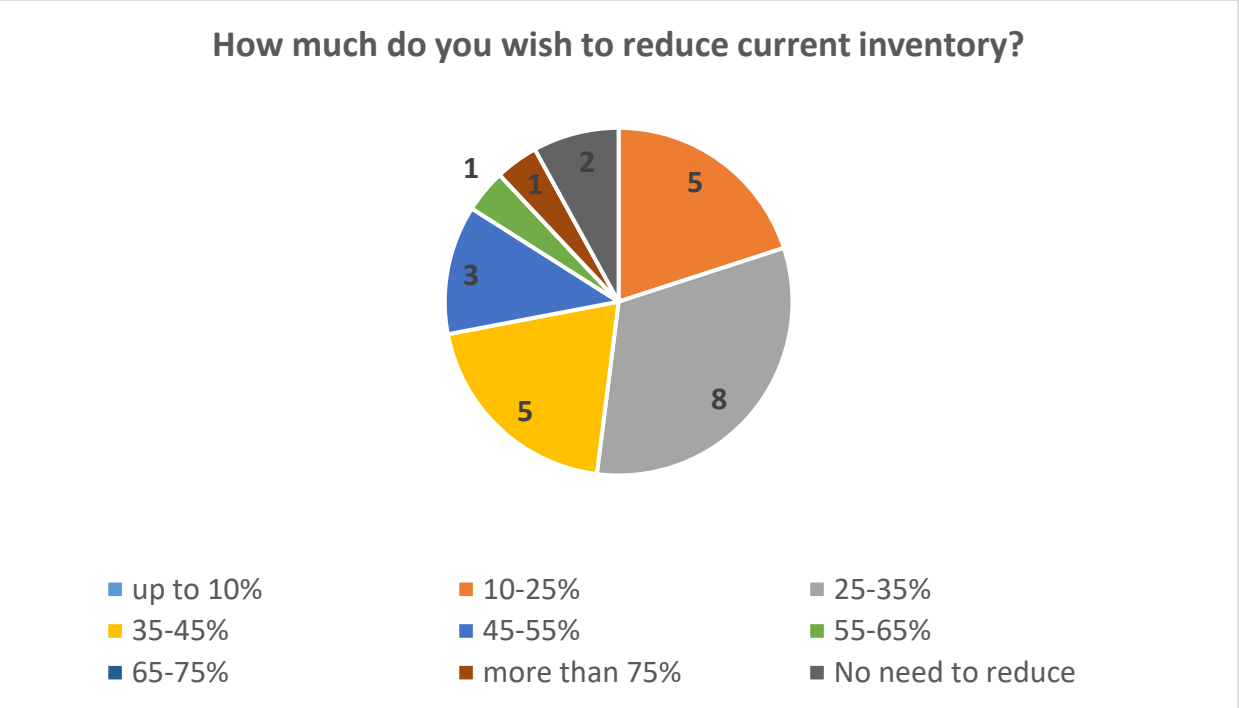


Table 18. Inventory statistics based on the survey. Developed by the author.

The theoretical part suggested that companies in Europe should reduce inventories by 60% (in4ma). Based on the survey it can be concluded that it is indicated that Estonian electronics industries want to reduce stocks on average by 25-35% Four companies wanted to reduce stocks more than 45%, five 35-45%.

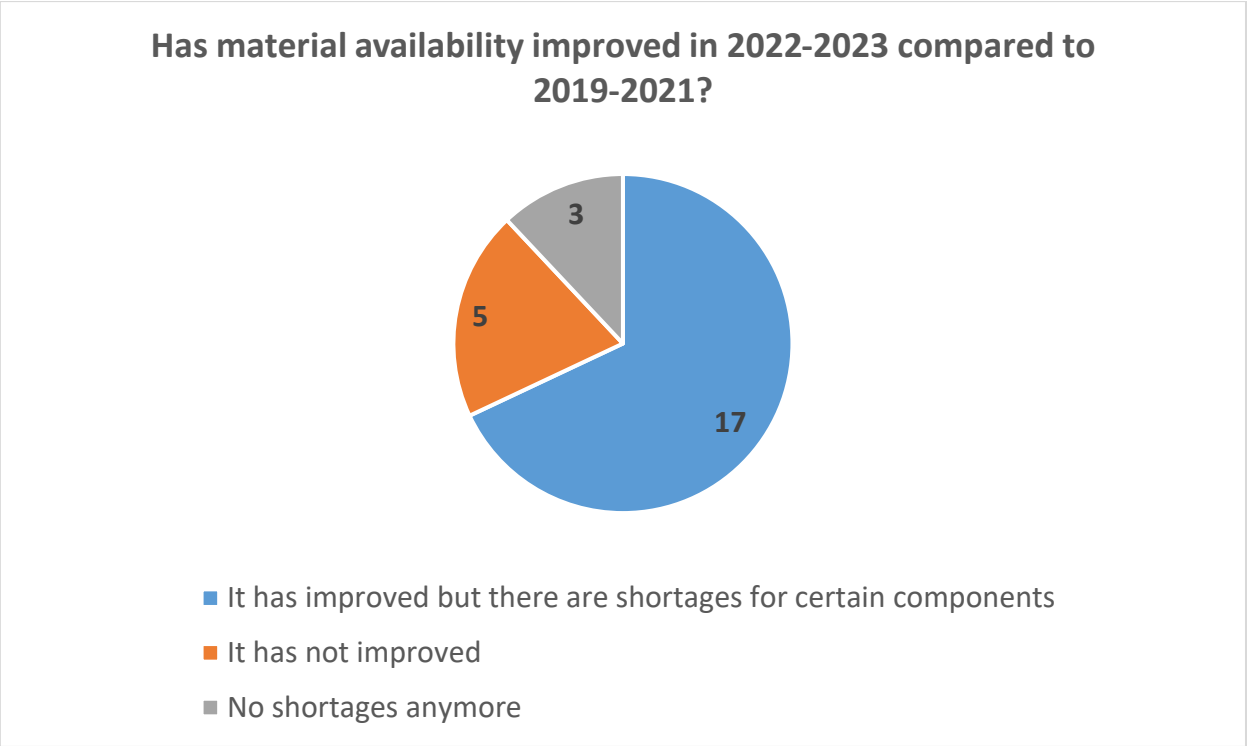


Table 19. Material availability changes. Developed by the author.

Most of the responders believe that component crisis situation has improved in the last few years, but shortages for certain categories such as microchips still persist.

Most important factor in material sourcing is price, in contradiction to inventory theorerical part, where it was stated that is some cases high delivery accuracy and short leadtimes are more important to be able to deliver than the price increases.

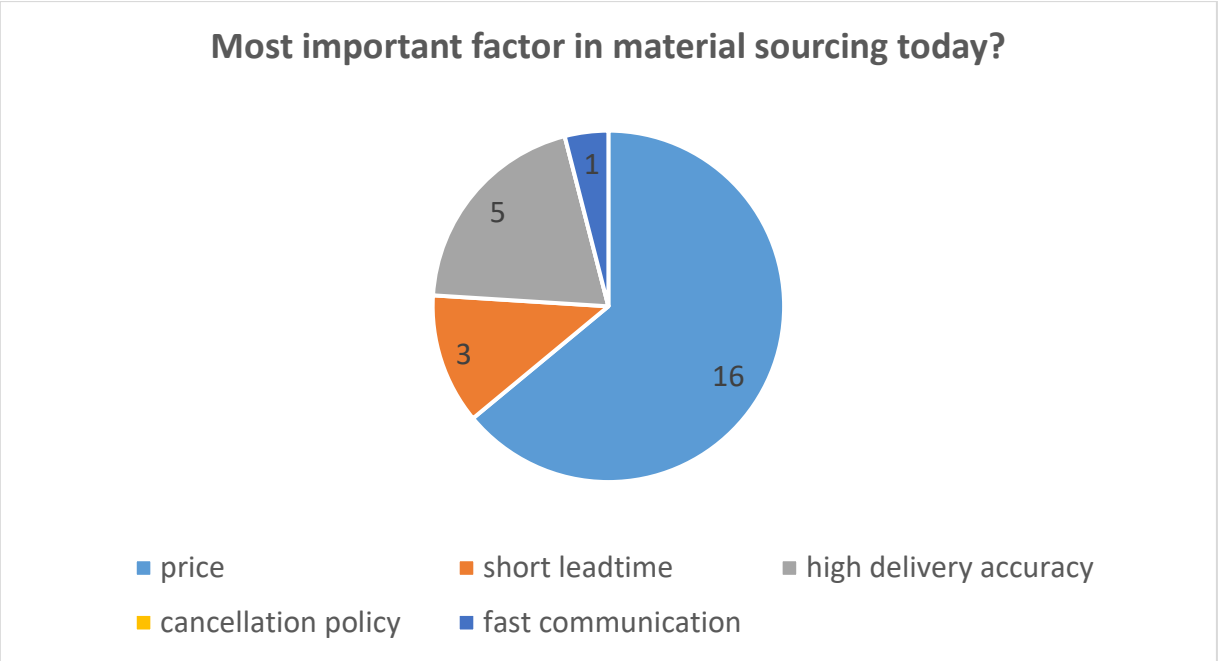


Table 20. Most important factor in sourcing. Developed by the author.

The current economical environment has impacted customer orders so much so, that most responders say that the orders have significantly decreased. The survey results and theoretical part indicates that this decrease is temporary due to the development of green tech and new technology, for example by 2040 all new cars need to be electrical. Market overview by compay Gartner forecasted semiconductor revenue to decrease by 11,2% in 2023 compared to 2022, but in 2024 it will make a 18,5% hike compared to 2023.

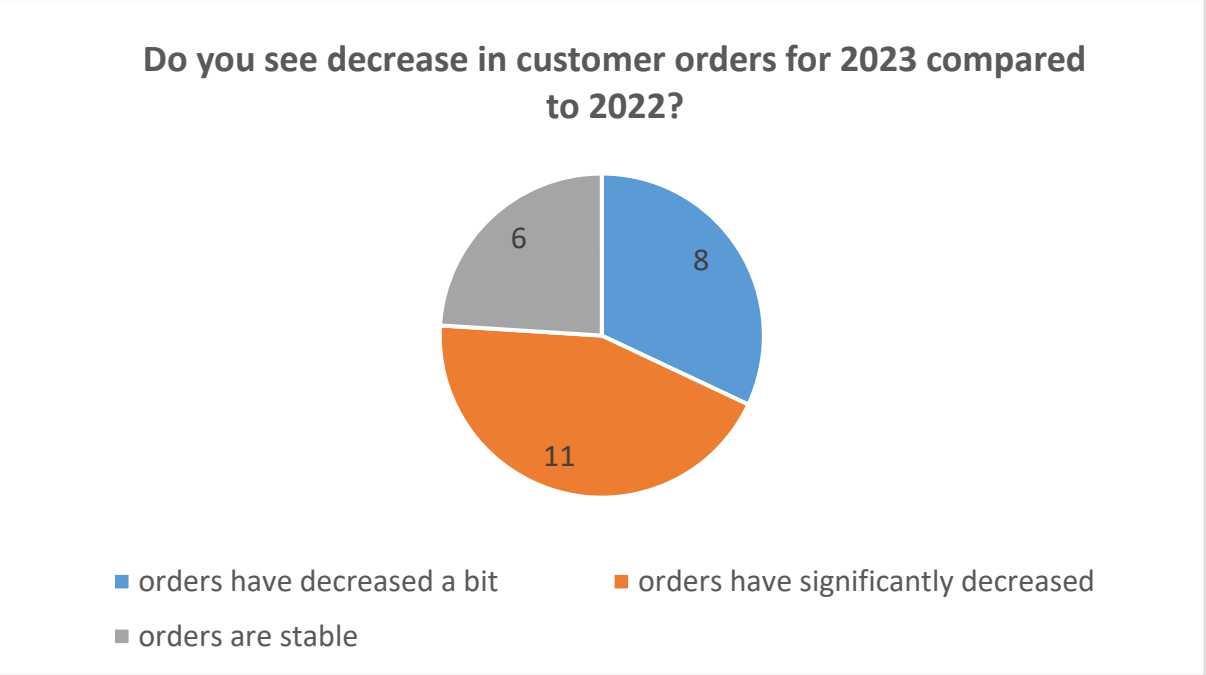


Table 21. Changes in customer orders. Developed by the author.

Overall, the big inventories are something all companies brought out. Main focus areas were adding alternative components and suppliers, cooperation with suppliers, identifying critical components and optimizing inventory stocks. Companies fo not find creating risk plans and training workers as important. Most of th companies have added alternative suppliers to Chinese ones and used the region for region approach.

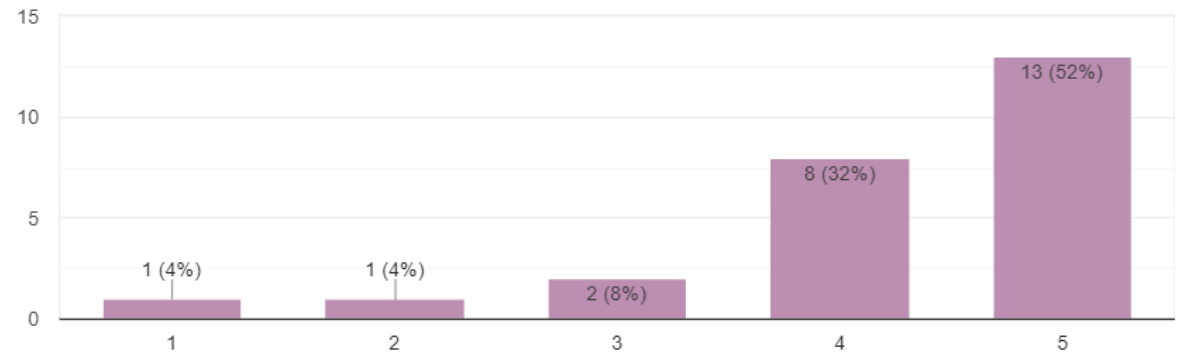


Table 22. Importance of digitalisaion and thus reducing manual work in supply chains. Developed by the author.

Almost all responders (21) valued digitalisation, automation and visualisation tools ins supply chain as it helps to reduce the added workload the crisis had created. Companies believe clearly that manual data transfer through excel sheets and outdated data visualisation needs to be improved to save time and make work more effective.

5. CONCLUSIONS

From below table author formulated proposals to Estonian electronics sector companies based on survey, theoretical and interview parts.

Risk	**Action points and proposals**
Production stops and shortages	• Improve cooperation with suppliers to know about shortages and accidents in advance • Standardise product designs • Approve alternative components • Map all tier suppliers • Train workers • Document new processes to risk plans • Identify critical components • Involve AI and digitalisation, usage of e-SCM tools in cost saving, risk and accident identification • Improve forecast accuracy • Approve manufacturers from alternative regions to China, check for the same manufacturers existing locations in other regions • Become more agile, be prepared to react fast

	• Involve whole supply chain to escalations to understand the root cause and coordinate info flow • Global cooperation
Undefined ways of working	• Define the new (and old) ways of working that emerged from the crisis into clear working processes, • Define KPI-s for new processes • Set a clear supplier meetings frquency • Agree ways of working with the suppliers and custiomers • Internal brainstorming for new tools and applicatons for automation • Create a clear risk management plan
Stockpiling and excess inventory	• Define the most critical and single-sourced components and keep bigger safety-stocks on those only • Keep lean principles for standardised products • Product designs with multiple use cases and standardised accessible parts • Analyse MOQ quantities and cancel excess inventory as a part of inventory optimisation

	• Improve forecast accuracy from customers and to suppliers
Increasing costs, workload and decreased demand	• Automate as much functions as possible • Use e-SCM tools and improve ERP systems to reduce amount of data sharing and visualization manually • Standardize product designs with more available products • Integrate sourcing and procurement knowledge and recommendations into product development phase and cooperate with internal product engineers to aoid costly mistakes • Cooperate with supplier engineers • Improve forecast accuracy • Analyse MOQ and inventories • Create common KPI-s and meetings with suppliers and customers
Unexpected risks - commodity price increases, accidents, lockdowns, political influences	• Assign a person or a team to monitor risks in a preventive way • Suppliers in different regions • Use AI and digitalization tools to get automated notifications and to map supplier locations

Table 23. Proposals for electronics industries. Developed by the author.

The survey indicated that companies had not documented their new ways of working into clear processes, which can cause problems in the future, for example when onborarding new workers or diferent ways of working inside the team. Having a clear risk management plan involves also documenting processes and translating new ways of working into new work processes. Also, the companies had not mapped out supply chain locations, only 6 responders had taken this preventative measure. Mapping out supply chain locations is especially important for single-sourced and critical components, because they are most vunreable in case if a risk realises.

Companies valued supply chain digitalization and automation highly and believe data transfering through excels and outdated visualisation should be improved in order to save the time and added workload the crisis created.

One of the most important changes that were implemented during the crisis was improved cooperation. It is important toet clear common KPI-s and meetings with the suppliers in order to keep the good cooperation as it is as a risk management preventative measure in supply chain. Another measures that were implemented during the crisis were adding more alrernative parts than there were previously, identifying critical componens and inventory stocks optimization.

The crisis resulted in overall high inventories, where 72% of responders wanted to reduce inventory stocks 25%-75%. This is why inventory optimization is an important measure to keep inventories under control and to keep the company profitable, as high inventories will lose value and expire over time, resulting in monetary loss, in addition to the increased warehousing costs.

The crisis is sill not over as shortages for certain commodities such as microchips still persists. This is also called the golde screw syndrome, which means one or two critical components are missing to finalize the products. Supply chains are impacted by events such as lockdowns, climate and political risks, therefore the risks will never dissapear. Customer orders have decreased due to inflationary environment and economical recession, but are expected to rise again in 2024 due to technological advancement and green technology growth. Most important factor in sourcing is still price, although short leadtime was increasingly important during the time of big shortages and not being able to deliver.

SUMMARY

The component crisis is not over as shortages for certain commodities still persist. One of such commodities is microchips and semiconductors. Europe has taken clear steps to alleviate microchip shortage by encouraging developent and manufacturig through investments as Europe as a technological leader is behind in that field compared to other countries. Most important factor in sourcing electonic components is price.

The supply chains have had to adjust to the rapidly chaning environment, creating added workload. This is why it is important to start to use e-SCM, automation and digitalisation tools in order to make supply chains more resilient and to reduce manual data forwarding through excel sheets and make data visually more easy to read. Companies have implemented measures such as increased collaboration, inventory optimisation, identifying critical components and adding more alternatives. Companies have not documented new ways of working into processes, mapped out the supply chain or created risk management plans as a result of the crisis. The effect of the crisis is extremely high inventory stocks, while 72% of survey responders want to reduce stocks significantly, up to 75%. Production planning was possible only short term, production stops were frequent and additional costs and spendings on transport and material were exremely high, although lean principles are still valid for standardised products and higher inventories or safety stocks should be kept for critical items such as single-sourced or long leadtime items.

Geographical concentration in electronics supply chains is dominated by Chinese suppliers due to available resources and low cost. One of main natural resources dominated heavily by China is rare earth elements. Steps are being taken to reduce dependency on Chinese REE-s and suppliers. European companies have started to use region for region approach, which means they are buying and making sure manufacturers are relocating or adding factories to different parts of the world such as India, Mexico or North Africa to avoid risks related to concentration in one region.

The role of souring managers in new product development phase is increasingly important, especially for smaller companies with less negotiating power and lower prioritization by the manufacturers. As the impact of crisis is tougher for smaller companies, they need to prioritise havier digitalisation, cooperation, automation and

adapt fast compared to large corporations who have more time to react due to competitive advantages.

One of the most impactful and difficult risks to manage is forecast accuracy. Most of the companies had received significantly different forecasts from the actual orders, which created the panic buying. Forecast accuracy can be improved for the standardised products only.

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APPENDICES

Appendix 1. Survey questions for the electronics sector companies

1. Do you think today's inventory levels are too high?
2. How much would you like to reduce warehouse stock and backorders?
3. How frequent have been the production stops from beginning of the crisis (2019)?
4. Have you had to make significant extra costs to continue the production due to the lack of electronic components?
5. Has semiconductor and microchip shortage been more impactful compared to other materials?
6. Please name the materials and manufacturers, which caused biggest extra costs.
7. Please describe how did the component crisis impact your company.
8. Have you had to adapt your production planning strategy based on component availability, not actual customer demand?
9. Has material availability improved 2022-2023 compared to 2019-2021?
10. Are lean principles still sufficient for production planning in todays market climate or should inventory levels be bigger than before?
11. How serious has been the impact of price increases to the procurement strategy of the company?
12. Which risk management strategies have you applied in supply chain management?
    a. Made sure that components/raw materials come from different regions or countries
    b. Approved more alternative components/raw materials
    c. Identified most critical components
    d. Identified most critical production orders
    e. Made sure that multi-sourcing is used and more than one vendor is used for materials
    f. Approved multiple designs to avoid high-shortage components

g. Updated or created risk management strategies/plans
h. Hired more qualified specialists
i. Made trainings for workers
j. Improved relationships and cooperation with suppliers
k. Improved relationships with customers
l. Updated insurance/increased insurance amount
m. Mapped locations of direct suppliers
n. Mapped locations of all tier suppliers (and raw materials)
o. None of the mentioned
p. Something else ….

13. Please mention if you have added alternative suppliers/manufacturers to the Chinese ones?
14. How important is the usage of new supply chain web-applications or systems to reduce amount of data forwarding through Excel?
15. Do you monitor market situation changes, such as future possible component allocations and shortages, raw material prices?
16. How did the component crisis impact cooperation with customers, manufacturers and suppliers?
17. How different has been the customer forecast vs actual orders due to the component crisis?
18. Do you see customer orders decrease for year 2023 compared to 2022?
19. Are Lean principles still valid for standard products or bigger stocks should be kept for critical components?
20. Which factors are most important in todays electronic components/raw material procurement?
21. Do you expect general price increase for electronics components in the upcoming year?
22. Which updates are necessary in electronics supply chains due to the impact of the crisis?
    a. Adding alternative components
    b. Involving sourcing specialist in product development phase
    c. Adding alternative suppliers
    d. Ordering from different regions
    e. Supply chain and supplier mapping
    f. Digitalization of the supply chain
    g. Improving cooperation with the suppliers
    h. Improving forecast for the standardised products

i. Identifying critical components
j. Optmization of the inventory
k. Cost effective sourcing/procurement
l. Standardized sourcing/procurement
m. Improving worker`s qualifications

23. Please mention if anything else needs mentioning
24. Please name size of the company
25. Please name age of the company
26. Please name field of activity
27. Please leave email address if you wish to have results later

Appendix 2. Interview questions

1. How has the electronic component shortage caused by COVID-19 affected your company?

2. Are there any changes in production planning, sourcing and purchasing due to the component crisis? *(production stops, planning according to inventory availability not demand)*

3. Have you had to make significant extra costs to keep production running and ensure material availability since 2019? Has the situation changed in recent years (2021-2022)?

4. Were the shortages bigger for microchips or semiconductors compared to other electronic components? How did it impact the company?

5. Do you think the lean principles for keeping inventory levels and planning production are valid in current market situation? *(Lean principles = to keep inventory levels as minimal as possible to reduce waste)*

6. Describe your company 's inventory levels at the moment, what is your inventory planning strategy?

7. Have you defined most critical items in terms of availability?

8. Are you continuously monitoring the market situation for new possible shortages or (raw) material price changes?

9. Have the actual customer orders matched the customer demand since beginning of COVID-19? Has it changed in recent years (2021-2022)?

10. What are the new ways of working and risk management strategies emerged from the crisis? *(new KPIs, approving alternative components, multi-sourcing, multiple designs, alternative regions, auditing suppliers, web applications for faster info sharing to replace excel sheets etc.)*

11. Describe how did the cooperation and relationships change with suppliers during the component crisis?

12. Have you approved alternative sources to Chinese ones for electronic components? Please bring examples.

13. Are you aware of the manufacturing locations of your suppliers? Do you know the manufacturing locations of all tier suppliers for the most critical items?

14. Do you have a supply chain risk management plan? Did you have one before COVID-19? Do you think you were well-prepared?

15. What have been your company's main strengths and weaknesses during the component and Covid-19 crisis?

16. What do you predict will happen in the near future in terms of the component crisis and product demands? Why?

17. Is there anything else you would like to mention?

Appendix 3. Interview questions answers with global telecom company

1. It has made a big impact on the way we had defined the way we purchased materials since COVID-19 started. The whole supply chain collapsed in a way because the factories were closed in China and and also, not only the electronic components were impacted, everything was impacted as well. So we had to redefine the way how do we get the materials in on time, in general the planning purposes **were changed so that we had to order much more in advance to make sure that the orders are placed and supplies are prioritizing us.** And e**specially with the ICC components there was no official lead time per say anymore. So we had to order a year or up to two years in advance, and then follow-up in order to actually get the materials.** And if the demand was increased then you had to pay a expedite fee. It's better to pay a fee to get materials in time in the in the warehouse. But for sure it had a really big impact.

2. I believe the toughest period was just when the COVID-19 started and also in 2021 in our industry, the industry was booming itself so that the demand was probably all time high whereas there was no way to get the materials in. So we were we were fighting hard with the shortages. We increased the safety stock levels based on the the demand at the time. **The demand of ours to the supplier had skyrocketed and we had to cope with the new reality. And then we had to pay a lot for it. We had to fly in the materials and we understood that this was the new normal.**

   And demand dropped then suddenly in 2022, when the war in Ukraine started. And the whole economy itself, kind of froze. So the demand didn't disappear, but it dropped a lot. And with the previous high demand in 2021 and with all of the added safety stock levels, this now meant that inventory levels are super high in 2022 and as well as this year in 2023. **The same stocks that we have previously planned cannot be fully used as the demand is not the same anymore and we have so much inventory**, so the planning and ordering in 2021 based upon these shortages has now made an impact. So and also from the sourcing perspective for the electronic components. I have heard that in some areas **with some suppliers in electronics they already have increased the prices by default to include some of the buffer fees**

because otherwise there is still no way to get them in time. Recently, the lead times have started to improve. So while previously these were like over a year now it's like roughly 1/2 year **but still, it if there are some demand increases, there is no other way to get them then pay the fee.**

3. Yes, for sure. In general, we do have yearly contracts with the suppliers where we agree upon the price for the next or the or following years, it's demand versus supply, right? So **if the demand overall for the electronic components is sky high versus the supply then supplier capacity is not enough. So that means that they have much more leverage on the prices. So it's not easy to reduce the prices here already over a year like we usually do. So for sure it makes an impact on on the regular price as well as then you need to pay an additional fee in case you have any demand increases.** So now we're looking **into how do we reduce these expedite fees as much as possible, as well as the how to reduce inventory levels overall and also redefine how do we make the safety stock target.** So in 2021 we wanted to buffer everything because the key to stay ahead of the competition was to be able to deliver. Supply was a competitive advantage in 2021 and **nowadays at the focus has shifted from being able to deliver, although it still remains, but now the focus is more on how to make profit and that has resulted in redundancies globally**, to reduce the cost, so not only to reduce the cost on inventories, **but also how to make things more efficient and digitalize, automate and make the positionas that are no longer needed redundant. So to make sure that the cost stays low.**

4. Yes, shortages were bigger for microchips and effects were overall similar as described in the previous answer.

5. In terms of lean it really depends on the commodity. The lean manufacturing does work for electronics if you have a steady demand. So if you have a steady demand, it's much more easier to plan and order these materials in advance so that you actually get them in time. But the more you have fluctuations in demand, the more it becomes closely impossible to have the lean methods in a manufacturing setup. So it's it's viable, especially in some areas. But let's say on the mechanics side we do continue to find a way. How do we continue to be lean, but at the same time now the focus is on **how to have more standardized products that you can use to add much more flexibility.** So we have more solutions how to use one specific product.
So, the product design itself has become more important now. Having a

design that can be used in multiple different ways and combined within this lean supply chain model is now the the key forward.

6. **Inventory levels are really, really high right now. We have ended up in an excess since 2021. So we are trying to first of all make a lot of intercompany sales.** So if new materials are needed at one location they first check the the internal stocks and warehouses. **And secondly, the safety stock levels, there are no longer as high as they used to be two years ago.** So when previously you wanted to have at least you know two or three months worth of buffer, now it has been reduced to either zero or, depending on the terms, of course, **if it's in a very critical material like these ICC-s, they will have some more safety stocks because you need to have some flexibility in terms of demand fluctuations. But that depends on the products, let's say so.**

7. Yes, of course we have, it comes down to the ones where we have the most problems with **so statically that I see of course you know electronics would be at the top of the list. So that items that have the longest lead time are the most important ones and then the the materials like mechanics that can have only few weeks lead time are at the bottom of the list.** So it wouldn't have a high safety stock target. Mechanics have low lead time compared to the electronics.

   So if it's a supplier that is single source in especially in like risky area that might get an impact by whatever reasons then they will also have a focus on not only finding the second source if it's possible, but we are trying to also mitigate the risk by looking for a second source and if that's possible if it's a single source. Or if they aren't, if there is no way to bring in the second source or you know for whatever reason, then you need to have some safety stock there as well of course, because if something happens with that supplier then you need to be now able to to have some weeks of stock to survive.

8. Yeah, we we have a whole department. Regularly we keep an eye on the commodities. **Also I think it was 2021 where we had an extreme increase in copper prices and to the extent that while we usually have a yearly agreements with the suppliers, but because our demand was so high and the copper price had increased so much and we had ordered the full yearly agreed volume already by end of April. And because it exceeded the early contracted volume, supplier actually refused to deliver anymore until we renegotiated with the new prices because of the**

copper price level. So they actually stopped deliveries. **So that's why you need to keep an eye on these commodity prices, because that may happen again. And by monitoring also the order intake versus what you have in the credible contracts is another thing that is important in the end.** I'd say that the the monitoring of the commodity prices itself has always been there at least as long as I've been there, for the past five years at least, so the sourcing department, they have always kept an eye on it. **But of course now within the past few years, it has become more prevalent.**

9. So I briefly mentioned it before, but in 2021, if you go back to that time, the business was booming, and customers they were ordering and forecasting really high numbers for 2021. So not only did we expect these developments to be had in 2021, we expected them continue over to 2022 and increase beyond because of the forecast increase from our customers.
In reality, that never happened. **Now because of the war between Russia and Ukraine the customers, they are holding back investments because they are afraid of what and how will develop further. Also what is the inflation going to do and what is the the overall impact in economy.** And because all of our sector is also heavily impacted by the way how a regular person is doing because of all of these price increases, the regular persons themselves are starting to now save more money, meaning that they don't order that many goods, meaning that the our direct customers themselves are not making investments because of that direct link with the global economy.

10. Yeah, we have a lot of risk mitigation activities and we are improving them. **One of the most important ones is we have a digitalized tool which monitors the current global activity. So if let's say there's an earthquake or if there is a lockdown in any of the countries, it automatically knows already where our supplier base is. You know, each part of the world, countries, cities and not only that, it also knows what kind of components are affected. So if something happens at any moment of time, whatever that may be, like I mentioned, it could be earthquake or lockdown, it then provides an automatic e-mail to us, and we can also monitor this on the website.** So it is needed to understand how big is the risk. **And also it automatically sends out an e-mail to that supplier about this event and then they will reply and everyone involved will know.** So that's one of the reasons mitigation activities will have been already mapped out then. **We also now have a focus on smart resilience, right. Like the product design. So how do we make this one product, especially on mechanic**

side, how do we make that one product more you know flexible in terms of having more use use cases. The more the one product is used in several different ways, the more you have options.

11. It changed a lot. So especially for me, I had like 30 different suppliers. When the shortages arrived and we had to redefine the way we work in securing the supply and fighting with the shortages. Almost all of my suppliers were having shortages when COVID-19 started, so we had to reallocate our own internal ways of working. We reallocated and increased our internal teams and with the suppliers, we had to also redefine the way we collaborate because of the amount of shortages. **So for instance, with suppliers, we made an Excel table where on daily or weekly basis we had a lot of product numbers that we were having shortages with.** We saw what was the demand and how much they could deliver and they also provided comments like what is their main bottleneck for each of the items and what actions they are doing to fix this shortages as well as when they believe they will be fully back on track.

    The general processes were redifined, but each person and each supplier defined those themselves, so it wasn't like official process that we would mark down and and document.

12. Yes we have. **Especially in terms of suppliers located in China. Add also beacause of the political environment and the relations between US and China.** For our US customers, having their suppliers located outside of China became become mandatory, **so looking for suppliers outside of China or the current supplies that are within China, for them to relocate to another other countries has become the key. So we have moved out a lot of items from China to to elsewhere or duplicated the factory locations. So we we may still have, let's say, the same supplier and previously it was only in China but has now opened a new factory in Mexico for example. Main locations have been India, Europe, Mexico.** Especially Mexico has become the key location for US demands.

13. So for that one, I mean the direct supply locations, that one is easy, and of course we know, but **the more you go down into the supply chain, the more difficult it becomes**. **For some products we know really well the whole supply chain if it's a product that we designed.** But if the supplier designed the product themselves, then of course, we wouldn't know exactly from where

this material has been sourced. But then usually if something does happen, that's the first thing that we ask, where exactly is everything coming from? What is the bottleneck, who is that supplier, where are they located.

14. I would say we've always had a supply chain risk managemenyt plan. That's why we have safety stock levels for. If there's some demand increases or sudden drops then safety stock and as much as possible, we want to have a second source.

    Because then again, if something happens with one supplier or we run into capacity issues, we can ramp up the other supplier, **but I would say no one was prepared for COVID-19.** It was these lockdowns, not only that it had impact on in the factories, but overall transportation as well.

15. We are such a big company. Most of the suppliers they were, struggling capacity, **but because we are such a big customer, it was much more easier for us to get priority.**

    And we can pay the expedited fees if need as long as we don't stop the deliveries to our customers. **In terms of weaknesses, I would say that the forecasting process itself, so the getting the accurate forecast from our customers. And then to turn that into orders and to have the forecast accuracy towards our suppliers,** that was I think one of the biggest weaknesses. So even if customers were providing forecast, they wouldn't even know if that would be turned out to be 100% true or not.

16. Yeah, I'd say if I knew that, I would be a millionaire. So I mean, predicting the future and if the prices will go up or down or what will happen in the future, no one would know for sure. **Depending on, you know, if something happens, if there's some sort of like an event that happens in the world, then that will depend on it.**

17. Mostly I would say that woking in supply chain has been a real rollercoaster and the recovery from pandemic and crisis situations has not been easy.

Appendix 4. Interview questions answers with IoT software and hardware applications company

1. Yes the shortage caused problems and confusion in production planning, purchasing, filling customer orders. We could not plan production efficiently it was always depending on one or few certain components availability and we did not know in advance what exactly we are able to produce and when.

   It also impacted our place in the market as a customer, we used to have all electronic components available in maximum 6 months leadtime, from distributors even earlier. But now it was very difficult because we did not have any estimated delivery time for orders placed even as long as one year ago. So we had to replan our way of working so that the supply team, production and our customers representatives were very closely collaborating and we had very frequent meetings discussing what we are able to produce in the end. We used to rely and get info directly from the ERP system but now we had to have daily meetings to recheck everything and to ask for updates.

2. It was not possible to make long-term production planning as before as purchasing opportunity for the missing components could have happened very suddenly and we had to react to that and change our production plans often accordingly and we managed to fill the customer orders and this made also purchasing and sourcing department work more difficult as we had to react very fast. Our company had grown very fast, was still growing rapidly and by that time the ERP we were using did not satisfy our needs as we did not have good visual overview, so we had to make additional excel files and found ways how to make better visual reports on what we are missing, what is the critical qty and by what time it is needed. We made internal company workshops to discuss which report or method of visualising was the best. We also had to buy smaller quantities with expensive price to guarantee at least some quantities to our customers. All the extra costs were subject to approval internally and we had to have very clear overview of those spendings as we communicate to our customers for what and when we are spending and our ERP system did not support that, so it caused a lot of manual work. We have a purchaser, sourcing manager and team lead who all need to approve and forward the extra costs. One example is that we used to buy one microchip component around 1 USD

per/pc but in crisis situation we bought it at 18 USD per/pc. Then we also approved costs in advance with the customer.

3. Extra costs were big and we had to share between us and customer. The situation is not so critical anymore but we still have problems with certain microchips and semiconductors. STM, Texas Instruments were problematic to name a few manufacturers.

4. Yes, costs and extra costs for microchips were certainly bigger than for other electronic components. Now sourcing managers have started to cooperate with engineers and have recommended to engineers to put more than one alternative to BOM and make everything more compatible so we do not have face any additional problems because of the material unavailability and so that everything would be more easily replacable if the most preferred component is not available. And for certain manufacturers sourcing has warned not to used them as they are not willing to cooperate or give even estimated leadtimes.

5. I think the implantation of lean depends a lot on which products are being produced. It is applicable for the "shelf products" but for example for customised module products, if we would have forecast in advance we could use lean approach but we do not have it, so for module products it is not applicable. So if there is a forecast we use it. We usually try to plan our production more in advance but as we are in a start-up phase and our customers are also in that same environment then we never know if our longer-term production plans become 100% reality or not. Then we buy electronics one year in advance and we do not do everything on the go, we make all orders one year in advance and then we follow up the backlogs. So for us it is not possible to buy according to the reorder point and the system really does not give purchase requisitions. So I hope we will have new system where we will have those requisitions and we would not have to cancel so many things and plan production better.

6. The inventory levels are very high and our money is so to say stuck under the high inventory. So we try to sell our excess stock to brokers and other interested parties. When we had a lot of PCBA-s ready then we pushed the client to make decisions where to use them and what product to produce and to whom to send. If it was "shelf product" then we tried to sell it back to the producer or to sell to customers or use as spare parts. We try to differentiate

what items in inventory have real value and which are excess, which we are not using anymore.

7. Yes, sourcing manager has clear overview of the components which are difficult to procure and is communicating this to customers and related parties. We have shortage report for each month which products are missing from inventory.

8. Yes, we collect a lot info from manufacturers or distributors to understand which are the latest trends. One distributor makes once a quarter pricing overview about pricing and inventory stocks, they are quite open about these topics now.

9. If there is a product that has increased demand because of the pandemic like one of ours did, the crisis was growth period. But now the situation has been calming down, the war in Ukraine started and economy is slowing down, so now we have to focus on reducing the costs and making some positions redundant as well. So keeping all that in mind, the forecasted quantities to this year will not fulfil anymore. We are not in the position where to force any forecast accuracy to our customers, we are very flexible and want to keep good relationships. Our customers also forecasted over their actual capabilities in terms of purchasing.

10. We needed to create visual reports and it pushed us to automate, to think which applications to use and which reports to create in google sheets for example. And when the demand increased our current ERP system was not enough. The sourcing manager is also pushing in production development phase that we should not use components that are very expensive or difficult to procure. **Now the role of sourcing is much more important and valued than before because the costs and difficulty of procurement has increased, so now already during new product development phase it is always coordinated with sourcing manager to make sure if it is possible to procure something within the expected leadtime and cost, not only after development phase, when the design is fixed.** We also used google sheets to have up to date info as well as Power BI.

11. At one point it was very difficult to have clear arrival dates from distributors as they said that they do not know why the dates are very unreliable and

changing very frequently and jumping forwards and backwards several months every week as it was depending on manufacturers info. As we are mostly buying from distributors we managed to solve this issue in cooperation as it is not fair that distributors take no ownership in securing the reliability of the confirmations. Also the suppliers engineers offered to collaborate with our engineers which was very helpful.

12. For electronics we used mainly local distributors. So we started to validate brokers from different countries such as England. So the distributors recommended brokers from several countries. But for mechanics we have started looking into closer regions as Europe, but it is difficult to proceed because the prices are not competitive which makes the supply chain more vulnerable.

13. The whole supply chain is clear for us, we know our distributors warehouse locations and we have overview of several manufacturing locations as well. When we meet with the manufacturers local representatives then they also help with the supply chain resilience. And they put a lot of effort into explaining why we have such difficult situation in terms of wafer supply for microchips for example, so they had whole process chains mapped out.

14. We were too small as a company before the crisis started and the crisis helped our business to grow so we did not need a very specific risk plan back then. And now we are trying to mitigate future risks by trying to mitigate the new ERP system.

15. Our advantages was that we were small and we still got our critical quantities from the market, so it was easier compared to big automotive industries for example who had big shortages. And also that due to the team being small, the teamwork was fast, quick and team was close, there were no corporate rules we had to follow that would slow down the processes.

16. Well a lot of the companies have money under the inventory so to say and the world economy is slowing down as well. But I think somewhere in 2025 when new technologies such as the electric cars become more advanced and economy will start to rise again, these shortages may reoccur again so we must be ready for the next shortages too.

17. Well I believe all manufacturers, distributors and all market parties are responsible for improving the situation, cooperation is important.

Appendix 5. Interview questions answers with electronics manufacturing services company

1. The leadtimes became long for many of the components, for example microchips leadtimes were around 1-2 years at least and orders were not fully confirmed, so the possibility of production really depended on microchips and other critical components availability. The extra costs to procure material were really high in 2022. Our customers also stepped in with escalations when needed and cooperation was very helpful in such difficult times. We also have few other factories in Asia and Europe, and cooperation and distribution of materials with those helped as well. We had to react fast for new cost-effective purchasing and sourcing opportunities.

2. Yes, we indeed had to plan according to material availability and we added a new KPI, which measures the accuracy of leadtimes. So we update leadtimes quite often, once in a month at least.

3. Yes we made big extra costs, especially in 2022, it was financially a very strong year for us as well. But in 2023 the costs have been rather low due to the economical environment cooling down and orders being pushed out or reduced.

4. Yes they were bigger for microchips and as mentioned before they impacted mainly production planning. We also go over the critical materials weekly. We discuss possible shortages we see for new BOM-s occasionally along the implementation stage.

5. Yes, in general they are still valid but we definitely need to keep bigger stocks for the critical materials.

6. Inventory levels are very high and we are trying to reduce those by minimizing the minimum order quantities we are ordering, selling stock and also cancelling unnecessary orders. It is sometimes quite difficult due to the cancellation conditions.

7. Yes, we have a separate spreadsheet where we monitor critical items weekly.

8. Yes, we are following London metal index for example, also market changes on component level.

9. No, not really. The forecast has been very fluctuating, sometimes below the actual demand, sometimes above. So in general the forecast has been helpful and given indication of course, but not very accurate as certain customers tend to forecast more than they actually order.

10. We have approved more alternative components and tried to consider critical components in new product designs as well.

11. Cooperation changed for the better. We started to meet more often and to share more in-depth details.

12. We are ordering through distributors, but it currently more cost-effective to order from Chinese suppliers. But manufacturers have started to build factories in alternative regions to mitigate risks.

13. We can get that information from distributors and for the direct suppliers we are aware of their locations.

14. I would not say we did not have a detailed risk plan, but we had clear processes and new ways of working that helped us to mitigate the situation better. But we are trying to update processes along the way. So we started having more frequent escalation calls, purchased inventory at least once year ahead for the critical components and monitored those in cooperation with clients and suppliers.

15. Our advantage is that we were reacting very fast to changing situation, adapted teams to be very proactive and we managed to keep production running by reacting fast to good offers and searching alternative components, but that meant frequent extra costs as well.

16. I think the crisis will slow down overall for now as companies have a lot of inventory, but it will continue for the microchips. In the future, with rise of green technology and improvement of economical situation it is likely that we will start to face shortages again.

17. I believe that being adaptive, collaborative and strategic in cost and inventory planning are the key elements in overcoming the crisis.