Navigating Uncertainty: Analyzing the Impact of the Global Chip Shortage on an Original Equipment Manufacturer's Strategy

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Abstract

Since 2020, the global semiconductor shortage has significantly challenged industries worldwide, with still no solution in sight to date. Especially the car industry has been struck hard, with a lack of semiconductors nearly bringing car production to a complete stop. This thesis explores how an Original Equipment Manufacturer (OEM) was forced to adapt its production strategy due to the chip crisis by examining which dynamic capabilities are necessary for them to succeed now and in the future. A pedagogical case study is used in which students are given a real-world scenario to assess an OEM's crisis management strategy. Semi-structured interviews with industry professionals, the OEM's product management team and secondary data were used to investigate the issue further. The findings of the thesis highlight three main points: (1) The need to modernize traditional car manufacturing by enhancing software integration in assembly procedures (2) The need to restructure supplier relations and the global semiconductor supply chain network. (3) The need for better risk management and order forecasting through evolving technology and sharing vital data along the supply chain. The thesis underlines both the beneficial and adverse implications of rapidly advancing technology on traditional car manufacturing and how this relates to a company's successful utilization of dynamic capabilities

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Resumo

Desde 2020, a escassez global de semicondutores tem desafiado significativamente as indústrias em todo o mundo, não havendo ainda uma solução à vista.

Especialmente a indústria automóvel tem sido duramente atingida, com a falta de semicondutores quase a parar completamente a produção. Esta tese explora como um Fabricante de Equipamento Original (OEM) foi forçado a adaptar a sua estratégia de produção devido à crise dos chips, examinando quais as capacidades dinâmicas necessárias para o seu sucesso agora e no futuro. É utilizado um estudo de caso pedagógico no qual os estudantes recebem um cenário do mundo real para avaliar uma estratégia de gestão de crises de OEM. Foram utilizadas entrevistas semi-estruturadas com profissionais da indústria, a equipa de gestão de produtos dos OEM e dados secundários para investigar mais aprofundadamente a questão. As conclusões da tese destacam três pontos principais: (1) A necessidade de modernizar o fabrico de automóveis tradicionais, melhorando a integração de software nos procedimentos de montagem (2) A necessidade de reestruturar as relações com os fornecedores e a rede global da cadeia de fornecimento de semicondutores. (3) A necessidade de uma melhor gestão de riscos e previsão de encomendas através da evolução da tecnologia e da partilha de dados vitais ao longo da cadeia de fornecimento. A tese destaca tanto as implicações benéficas como adversas de uma tecnologia de rápido avanço no fabrico de automóveis tradicionais e como isto se relaciona com a utilização bem sucedida de capacidades dinâmicas por parte de uma empresa.

Título: A Navegação na Incerteza: Análise do Impacto da Carência Global de Chip na Estratégia de um Fabricante de Equipamento Original

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Palavras-chave: Capacidade Dinâmica, Falta de Chip, Gestão de Risco, Planeamento Estratégico, Efeito Bullwhip, Gestão da Cadeia de Abastecimento, Vantagem Competitiva

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List of Abbreviations

CA	Competitive Advantage
DC	Dynamic Capabilities
JIT	Just-in-Time
JIS	Just-in-Sequence
KPI	Key Performance Indicator
OEM	Original Equipment Manufacturer
PM	(The) Product Management Team
RBV	Resource Based View
R&D	Research & Development
SC	Supply Chain
SMC	Supply Chain Management
TSMC	Taiwan Semiconductor Manufacturing Company
UMC	United Microelectronics Corp

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1. Introduction and Methodology

What is it that a washing machine, a fitness tracker, and a VW Golf[1] have in common? All of them only function with semiconductor chips. The tiny silicon chip has taken a firm grip on the world of technology and electronics: The more digitally advanced the world becomes, the more semiconductors are needed - in the US alone semiconductor chips are the fourth most traded product (Tentori & Guidi, 2021). The industry hit an absolute record in 2021, shipping 1.15 trillion chips (Semiconductor Industry Association, 2022) - even though there still was a global chip shortage - showcasing the semiconductor's growing role as the backbone of the industrial world.

It therefore came as no surprise that a sudden shortage in the supply beginning in 2020 disrupted not only one but multiple industries that depend on chips for their products. Covid-19 related shutdowns, as well as natural disasters in Asia, forced key semiconductor industry players to temporarily bring their production to a halt. This in turn had a tremendous effect all along the global supply chain. One of the industries that was hit the hardest was the automotive industry: With rising demand for new vehicles and development towards more electric and battery based cars, automotive manufacturers found themselves in a very tight spot once the supply of semiconductors came to a near standstill. On average, a car contains around 1.400 chips that control everything from brakes to the airbags (Semiconductor Industry Association, 2021). Nearly all car manufacturers were forced to produce with a bare minimum of necessary semiconductors whilst handling fluctuating consumer demand that was shaped by external events, such as Covid-19. For some manufacturers this meant that their profitability was hanging by a thread. In this thesis the strategy adaptation of an anonymous car manufacturer in the wake of the chip shortage will be presented and analyzed.

The thesis will be in the form of a case study. Case studies are "used as a metaphor for a larger - and more general - class of business problems" (Roberts, 2001, p. 1). In this case the business problem or phenomenon is the transformation of an individual international car manufacturer's production strategy while facing the current chip crisis. A high-level automotive industry analysis will be followed by a more in-depth look into the company's profile and deep dive into the company's product management team. After analyzing the usage and importance of chips in the automotive industry, the causes of the chip shortage as well as the characteristics of the automotive supply chain will be addressed. To provide a

[1] The choice of the car model is random, and no statement about the OEM can be derived from it

theoretical background for the case study, important conceptual, theoretical, and strategic frameworks will be discussed. Finally, an analysis of the case study in the form of discussion questions and answer guidelines are presented.

1.1 Methodology

The goal of the case study is to examine how a major car manufacturer's production strategy was affected by the chip crisis and how this strategy was modified to prepare them for potential future challenges. To do this, a qualitative research approach was used, obtaining primary data through seven semi-structured interviews. For qualitative research, semi-structured interviews are the preferred method since they give researchers more flexibility to thoroughly explore different topics and questions in detail (Drever, 1995). Given the nature of the thesis (case study) this interview format was chosen to analyze whether the new strategy implemented by the car manufacturer helped them deal with threats and maintain their competitive advantage for the future. The interviews were conducted with the HeadQuarter product management Team's employees and industry experts from other original equipment manufacturers. A guideline and summary of the key takeaways from the interviews are provided in the appendix. The interviews were held in the native language of the participants, which was German. Additionally, secondary data, in the form of reports, factbooks, interviews, articles, whitepapers and working papers, were employed to strengthen the study's exploratory nature.

In Table 1 the data sources of the thesis are summarized:

Data Source	Amount	Format
Interviews	7	Employees at OEM and experts from further car manufacturers
Media Articles	20	Press Releases, Interviews and Articles
Firm Internal Documents	6	Reports, Factbooks
Whitepapers and Working papers	9	Institutional Reports

In Table 2 the anonymized interview data is summarized:

Interview #	Date	Time	Role of Interviewee
1	4th October	5:30 pm	Team Lead Product Management HQ
2	6th October	4:30 pm	Expert Policy & Business Development in automotive industry
3	14th October	5:00 pm	Team Lead Product Management HQ
4	20th October	6:30 pm	Expert Policy & Business Development in automotive industry
5	21st October	5:00 pm	Employee at Product Management HQ
6	22nd October	3:00 pm	Employee at Product Management HQ
7	23rd October	4:00 pm	Expert Business Development at OEM

The product management team and industry experts have requested to remain anonymous due to the delicate nature of the chip shortage in regards to the OEM's company strategy. Hence the numbers used in the case have been altered to protect the identity of the OEM.

2. Case Study

2.1 Introduction to the Industry and Company

Today's economies are constantly evolving, driven by digitalization, rapidly developing technology, and changing societal requirements. This change also applied to the automotive industry, which in 2020 - as one of the largest industries worldwide - accounted for 3% of the global economic output (Cohen, 2021). The last few years had put the automotive industry to the test, dealing with external and internal issues disrupting the industry: Covid-19 related restrictions, shutdown of factories, workforce lay-offs, contracting global economy, decline in new vehicle demand and global bottlenecks in supply chains. Consequently, global car production dropped 15.4% in 2020 compared to the previous year (Knoema, 2022). However, positive trends were also influencing the industry: Increasing automation, autonomous driving and battery electric vehicles (BEV) were a few movements that impacted the industry's future outlook.

In 2020 the product management team of a multinational automotive company in the premium and luxury segment was forced to redesign its strategy, as a global shortage of semiconductor chips left them with essential pieces missing for their car production. Without these chips, the OEM would need to reduce production potentially right up to a complete stop. This would result in losing out to competition, not meeting their customer's demands, potentially losing clients, risk a decline in revenue and damage to its reputation. Semiconductors are "highly specialized devices that provide[d] the backbone for any electronic product to operate" (Wallach, 2021). Even though they are only a few millimeters wide, their importance in today's world is immense: Laptops, smartphones, cars, planes, medical devices, military systems, industrial machines, data centers, electronic consumer goods to watch movies, listen to music or play games on and many more all need these little chips to function (Semiconductor Industry Association, n.d). On average, between 1.300 and 1.600 chips were used in the manufacturing process of a standard car (Hackmann et al., 2022.), with double the amount needed for BEVs. While the demand for new vehicles dropped at the beginning of 2020, it perked up again quickly in Q2 of 2020. So halfway through 2020 the production management team faced a major issue for their ongoing production line: important components were still missing, yet they had to continue producing to remain competitive and meet their customers' demands.

2.1.1 The OEM's Mission

The OEM was founded in the early 20th century and had quickly gained global dominance: its production network was growing in over 18 countries, and the sales network expanded to more than 135 countries worldwide. At the beginning of 2020 they held roughly 15,5% of the market shares in the global automotive market. The company set out to be the top supplier of high-end items and services to facilitate personal transportation. To achieve this goal, they were constantly evolving their production portfolio (e.g., recently towards BEVs) and their production capacity.

One of the core strengths of the OEM was its R&D department which was constantly seeking new innovations and using their technology to enable the company to grow continuously. Paired with a strong global position and a key focus on business development, the company was known for manufacturing high-quality premium products that generated high revenue and profitability. However, the company was also facing internal and external challenges threatening its expansion plans: Internally, they experienced a decline in the operational performance, with the operating margin dropping from 8,4% in 2019 to 5,1% in 2020. Intense global competition, managing the complexity of rapidly changing technology, and foreign currency risk were further external challenges for the OEM. Additionally, the car manufacturer’s production process was highly complex and cost demanding. Due to the chip shortage, the company’s competitive advantage in producing high quality cars was put at risk. Therefore the PM had to redefine the company’s production strategy in the short term to find the ideal allocation of limited chip supply to their product portfolio, and in the long-term to ensure a more robust set-up.

2.1.2 Introducing the Production Management Team

Working at the headquarters, the PM was responsible for all global product-related topics. On the one hand they were taking care of the upcoming product portfolio; on the other they were supporting the current running production with any major decisions and/or issues. In their role, PM functioned as the interface between sales and vehicle development: They managed the requirements of their clients in all global markets and forwarded these to the factory and actual vehicle production teams to ensure that the market’s requirements were implemented in product development. The most important markets they were dealing with were the USA, China, and Germany.

Concerning future production, the PM would meet in regular workshops with the markets to discuss their requirements for the vehicles in the next 5 years, i.e. setting out the production roadmap for the next car series that was being manufactured. The challenge they were facing was that as a big and globally represented vehicle manufacturer, PM had to cater to all interests of the different markets successfully. In this decision-making process several variables were of interest: production volume in a particular market, potential revenue to be gained, cost factors, technical feasibility, customer requirements, market-specific approvals, and more. Next to the markets, the PM was also in daily contact with vehicle development and production. This was primarily done to confirm whether the solutions established with the markets were technically possible. Given the industry’s rapidly evolving trends towards digitalization, electric cars, autonomous driving, and sustainability, these interactions were becoming even more important for the PM.

Equally important, the PM also had to manage the running line of production, making sure that the market's requirements were met and dealing with issues affecting the current production. In 2020, when the first suppliers of the company started having issues producing the required amount of chips, as they were not being delivered the needed components, the OEM's purchasing unit had to reach out to PM to inform them about the situation. To avoid severe hits on the production, an immediate reaction was necessary by the PM.

2.2 Crisis: Chip Shortage

Even though the pandemic had already brought grave challenges to car manufacturers, the OEM was suddenly hit by a much more intense problem: Semiconductors that were vital for producing their cars could not be supplied. To understand the weight of this issue and its potentially far reaching consequences, it is important to understand how the OEM used semiconductors and what exactly happened in the first half of 2020.

2.2.1 Role of semiconductors in car manufacturing

On average, each vehicle consisted of up to 30.000 individual parts, which the OEM sourced from up to 12.000 suppliers globally. In order to secure the stable and highly optimized supply chain, each car required diligent planning, engineering, and manufacturing. In this production process semiconductors played a key role: Depending on what equipment was needed and requested in the car, each car held several thousands of semiconductors essential for its electronic devices to function (Schillmoeller, 2021). Roughly twice the amount was necessary for electric cars. Chips were used for example, to regulate the braking system, engine control, enabling headlights, wireless charging systems, emission monitoring, air conditioning, automatic seat settings, keyless access, controlling airbags and assistance systems, amongst many more functions (Köllner, 2022)[2]. The semiconductor market was highly competitive as there were only a few companies that manufactured these chips, such as TSMC, Nvidia, Intel and Samsung, with more than half of all chips used worldwide coming from Taiwan (Schönfeld, 2022).

The OEM acquired the chips from multiple suppliers, with each chip holding a unique software and building structure that had to be considered when implementing it into the car. Hence if a specialized chip was absent, it was difficult to simply replace it with another, as the software would have to be overwritten and adjusted to be able to function within the particular car. The process of overwriting software on chips was outside the capabilities of a typical car manufacturer. Consequently, even if all other parts of the vehicle were available a single missing chip could lead to a complete stop of car production. According to industry experts,

[2] See Exhibits 1 & 2

most traditional car producers did not have a central computer that controlled and monitored the individual chips within a car[3], hence they had thousands of individual software for each chip that had to be monitored. As such a traditional car manufacturer, the OEM had little to no integration between hardware and software. Rather, they were both dealt with separately, which only enhanced the dependency on these specific chips for their production. Additionally, the capability of integrating software and hardware had been outsourced by traditional OEM's, making a quick response much more difficult.

2.2.2 Chip Crisis

Two key elements set off the chip shortage: (1) Change in consumer demand and (2) manufacturing bottlenecks.

With the beginning of the pandemic in 2020 and the subsequent global lockdowns, consumer demand for new vehicles dropped rapidly, as consumer's transportation needs changed (Tummalapalli & Robinson, 2022). Fewer cars were purchased and consequently, the OEM's demand for chips declined as well, as they had fewer cars to produce. The automotive semiconductor industry saw a significant decline in sales between 2019 and 2020: In 2019, the industry had a revenue of 40 Billion USD, which slumped in 2020 by -5,1% to just over $38 billion (Amsrud, 2020)[4]. At the same time, a shift towards consumer electronics, home electronics, and personal computers expanded tremendously as the pandemic led to an increase in remote working and online education. This caused chip suppliers to seize the opportunity and reallocate their production resources towards these highly in-demand-products[5]. This turned out to be very profitable for the semiconductor industry, as they earned higher margins on high technology chips instead of chips needed for the automotive industry. In 2020 TSMC - one of the main global chip suppliers from Taiwan - earned around 50% of its revenue from chips manufactured for mobile phones, but only 4% from chips used in cars (Hille & Inagaki, 2021).

However, in the second half of 2020 car sales strongly picked up again worldwide, leaving the automotive industry in dire need of chips to meet the demand for new cars. With the semiconductor industry's allocation of products to other industries the automotive segment found less supply of chips than needed to fulfill their demand. Therefore the OEM was no longer capable of configuring new cars the way their customers had requested and in some

[3] See Table 5
[4] See Exhibit 3
[5] See Exhibit 4

cases even already paid for. Consequently, they had to change 46% of the car orders, as not all components could be provided in time for the production[6].

Apart from the fluctuating demand that made it increasingly difficult for the OEM to manage its desired chips volume, bottlenecks in the global supply chains were also slowing down the production of semiconductors. Pandemic-related localized shutdowns of factories led to production shortfalls, with orders for semiconductors reduced accordingly and in some cases even canceled altogether (Boranova et al., 2022). This also impacted the expansion of chip production facilities to match the growing demand and increase their capacity, as Covid-19 regulations seriously restrained construction. In the wake of this crisis, the increasing dependency on single-country sources of supply, especially from China and Taiwan, became obvious[7]. In 2000 China accounted for 5% of global semiconductor manufacturing. By 2020 this percentage had increased to 30% (Hofstätter et al., 2020). The Taiwanese market share of global semiconductor manufacturing was 15% in 2020 for "normal" chips and 92% for advanced semiconductor manufacturing (Varas et al., 2021).

Additionally, the manufacturing of semiconductors was a very time-consuming process: the lead time (the gap between production and being sent to customers, i.e. OEMs) was on average 4 months, given sufficient capacity was available for production. If this was not the case the production could take up to 18 months (Burkacky et al., 2022)[8]. The geographical concentration of chip foundries in Asia paired with long lead times already limited the flexibility for the OEM and made it difficult to respond quickly to their customer's varying demands in 2020. This also harmed the client's satisfaction: The client's loyalty was tested as delivery times for cars started at 6 months and were in some cases up to 2 years, without a guarantee of possessing all requested features (Schönfeld, 2022). Selectively leaving out chips within the car production was not the best option for the OEM as their sensitively balanced production chain was not designed for this (Schönfeld, 2022). Also, there were fundamental elements necessary for the car to function and therefore these had to be supplied with semiconductors.

The chip crisis was kicked off in 2020 by external shocks, such as Covid-19. In addition, decreasing global car demand at the time led OEMs to also reduce their semiconductor orders. The suppliers in turn saw a decline in orders and made their forecasts (based on this order information) on their orders for raw materials. This process then moved along the

[6] See Table 4
[7] See Exhibits 5 & 6
[8] See Exhibit 7

manufacturing process and led to a distortion of information, poor product forecast, insufficient capacities, and in the end, product unavailability. The phenomenon, known as the bullwhip effect, amplified the gap between available supplies and demand for semiconductor-enabled products. As demand for cars sharply increased again in the second half of 2020, OEMs faced a significant chip supply shortage. Combined with the reallocation of chip deliveries to other industries and bottlenecks in the supply chain, this magnified the crisis. Therefore the PM needed to determine swiftly how to continue producing with insufficient capacities.

2.2.3 Supply chain characteristics of the semiconductor-automotive industry

The automotive-semiconductor supply chain has become increasingly complex and sophisticated over time, surpassing the complexity of other industries' supply chains (Frieske & Stieler, 2022). The standard supply chain "pipeline" went from customers to OEM to Tier 1[9] suppliers (e.g. Bosch) to further suppliers along the chain (Tier 2,3,..n) until contract manufacturers of semiconductor chips.

Over the years, the OEM had highly optimized and updated its supply chain process for semiconductors to achieve high efficiency and gains in productivity. There are several characteristics of the semiconductor-automotive supply chain that impacted the production strategy of the OEM:

(1) Only a handful of contract manufacturers, so-called foundries, converted raw materials into advanced semiconductor chips (Hahne, 2021). Therefore these materials were already scarce, and this had to be taken into account for the production strategy
(2) Global sourcing, i.e. striving for the most cost-efficient production, led to just-in-time and just-in-sequence processing being the traditional operational processes for the OEM[10]. This strongly reduced inventory and storage costs and demanded highly planned logistics: The OEM relied on components arriving at the right time to be used immediately in the assembly process. If not, this would result in a stop of production as they were only able to continue with the pieces.
(3) The semiconductor-automotive supply chain was highly vulnerable to disruptions. Any issue would cause a ripple effect along the chain that impacted all companies (as described in the previous chapter).

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[9] Tier 1 suppliers are firms that business is directly conducted with
[10] See Appendix for further information

Hence the unexpected shortage of chips resulted in an immediate disruption of the entire supply chain (Burkacky et al., 2021), forcing the PM to rethink their traditional semiconductor procurement strategies (Dixon et al., 2021) and how to maintain their current assembly of vehicles.

2.3 Adapting the Strategy

2.3.1 Strategy before the chip crisis

The OEM constantly faced uncertainty about how future developments and trends may influence the automotive industry Consequently, they had to adapt and improve its strategy and identify and monitor challenges and opportunities to hold its competitive advantage. As a large company with international positioning, the OEM's conflicting goals consisted of achieving optimal cost efficiency by globally standardizing their products and meeting the heterogeneous markets and individual customer requirements within their product portfolio (e-mobil BW GmbH et al., 2022).

Therefore they were constantly aligning their company goals with external factors based on the constant rate of change in their business environment. When deciding the future production strategy, the PM had to consider several factors: Trends and movements within their markets and the industry, e.g. moving towards BEVs, manufacturing lead times, development periods, and car model life cycles. Four to five years before the production started, they began the production and investment planning process. Until the total production capacity was reached it could take up to eight years (e-mobil BW GmbH et al., 2022). Hence, their strategic planning process was oriented toward long-term goals.

Previously, the PM was following a two-stage strategy concerning the production process. Two key factors that differentiated the different stages were time and urgency.

The first stage was called an orderly process and was used under normal circumstances. During this process, the PM would meet up with the markets they were operating in to discuss the requirements and interests of their clients and how to introduce this into their upcoming production line-up.The following topics were considered: Demand trends, regulations put into place in respective markets, new areas of development, and issues that affect production. The markets provided the PM with accurate feedback and trend analysis, because of their ongoing customer contact. The PM could then assess the scope of the issues and determine whether they influenced the production line-up. After meeting with the markets, the established plan-of-action would have to be approved by a decision-making body within the OEM and then implemented for their next global production line-up. For changes and issues concerning the current production line-up, a similar process took place, except that adjustments were implemented in the following month - pending approval.

The second stage was known as the emergency process. This was initiated when faced with more urgent issues that needed to be dealt with rapidly - often within a few days up to a week. The PM also referred to this as the stamping process: If a topic was brought to PM by the markets that was crucial and impacted the running production, immediate action had to be taken. The PM stamped the production log of the car types affected by this decision. When the car was on the assembly line, the factory would be notified that it had been stamped and hence the car would be e.g. produced with certain deviations. This was mostly only a temporary solution and the OEM would follow up later on in the process to ensure a completed production of the car. A severe implication of this process was that it likely led to customer frustration. Therefore, the PM would have to consider further strategic options when the emergency process was chosen. The first option was to allow for a price reduction for the customer as they could not deliver a car fulfilling the (paid-for) requirements of the client. The second option was to consider re-fitting the car once the missing parts became available again. Before deciding on the second option, the PM had to align with vehicle production to ensure that this was even technically feasible and if the missing component was considered critical or the car could function without it.

2.3.2 Adapting their strategy

In the face of the chip crisis, the management level of the OEM decided that the production strategy urgently needed to be adapted to avoid production stops and loss of revenue. The PM was already operating at the interface of conflicting forces (supplier and clients), with very demanding and complex conditions that were only inflamed by the chip shortage. Whilst commonly anticipating market demands in the early stages, planning for various scenarios, and managing risk effectively, they had yet to be able to do so for the consequences the shortage brought. With the chip crisis, it was difficult for the PM to anticipate further consequences as the implications were still ongoing and there were no means to accurately forecast what would happen in the coming year or two. On a short-term basis, the OEM's purchasing unit tried ordering and getting as many chips as possible, even reaching out to new suppliers or going directly to the market to purchase chips as broker products. After these steps, they could establish more accurately for the PM how many chips were left for the running production of cars and how long this would last. With the scarce chip inventory, the PM had to allocate the resources and redirect their strategy by expanding their R&D Capacity, enlarging their supplier network and performing vehicle-specific and regional adaptations.

i. Expanding R&D Capacity

In response to the ongoing chip crisis the OEM initiated strategic investments of up to 25 billion euros into their R&D department. This decision had two primary goals:
Firstly, develop new products and foster innovation, especially in terms of electric mobility and autonomous driving. Secondly, improve existing products and assembly processes. By reaching these goals, the OEM wanted to achieve milestones along the way: With the investment, the dependency on certain semiconductor chips should be reduced in the future. Continuing its strong focus on R&D, the OEM started processes of integrating hardware and software in the car assembly and developing its cars into a more electronic engineering product rather than a mechanical one. Another milestone was to improve supplier relations and procedures by introducing tools and solutions to increase visibility along their production supply chain. By achieving these milestones, the OEM wanted to become capable of equally developing and combining hardware and software. This was after all a capability some car producers had already gained before the chip crisis enabling them to work with alternative semiconductors without having any significant impact on their production.

ii. Expanding Supplier Network

The chip crisis clearly highlighted the single-dependency of the OEM on semiconductor suppliers and factories in the Asian market. This resulted in complex logistics that - combined with long lead times - strained the OEM's flexibility to react to unexpected external or internal events.
A short-term strategic response of the PM was to stock up on inventory: moving from Just-in-time/just-in-sequence to just-in-case deliveries, i.e. having enough supplies in case they were needed. Even though this implied higher inventory cost, these outweighed the loss in profit of not being able to produce at all - on a short-term basis.
To improve their long-term operational flows, the OEM initiated further strategic partnerships with chip suppliers, focusing mainly on geographical proximity to its production sites. By getting chips from nearby factories, the impact of unforeseen disruptions would be softened and the shorter logistical routes would enable the OEM to react more efficiently and faster. The aim of spreading their supplier network was to mitigate their dependency on single

suppliers and to ensure planning reliability concerning the necessary chip volumes. In 2021 the OEM hence signed agreements with three main chip manufacturers. These direct supply agreements meant they skipped the Tier 1 supplier and targeted the second tier, i.e. secondary battery producers. Collaborating more closely with the suppliers further down the supply chain enabled a new level of visibility for the OEM. This created a flexibility to better forecast supply variations and respond more swiftly in case of issues and /or bottlenecks that impact the production of the OEM. Furthermore, with these direct supply agreements, the OEM managed to strategically position themselves to access raw materials needed for the production more easily. Therefore they could synchronize capacity planning directly with developers and manufacturers, gain visibility into the supplier's production progress and adjust their own forecasts accordingly. In the future, this will help the PM to better plan for their upcoming production and be able to anticipate potential shortcomings early on.

iii. Vehicle-specific adaptation

With essential chips missing for the production, the PM knew that they simply could not meet the demand for all car models within their company. Based on their brand image as a sporty premium and luxury car producer, the OEM aimed to optimize their profits and secure the overall financial performance while dealing with the chip shortage. The OEM's car portfolio varied from subcompact cars (mainly under four meters with a four-cylinder motor), over convertibles, electric cars to full size SUVs (six-cylinder motor with state-of-the-art equipment and latest technology). From their entire portfolio, it was their luxury SUV series that was best delivering on their brand promise: the size of its engine included sport features and technologically advanced equipment produced at the highest degree of excellence. The PM therefore decided to prioritize premium models in the running production, as they generated higher profit and margin. Hence available chips were mostly allocated to the production of those SUVs instead of smaller models, with the OEM shifting their focus to expand the upwards model range. With this decision, the PM knowingly limited the production of more affordable cars that often also had high sales volume. Consequently the sales of the luxury SUV went up roughly 7,2% in 2022 compared to 2021, whereas the most basic model from the standard division went down by -35% between 2021 and 2022. Given the uncertainty on how the chip shortage would further unfold and consequently affect the profitability and production efficiency of the OEM, the PM based their chip allocation strategy on securing their financial stability.

This also signified that other models would either be discontinued or sold with long waiting and delivery times. Clients that had ordered a more standard model were given the following three options: (1) Taking the car as it is (minus certain components), (2) waiting until the car with all its features would be available, taking into account prolonged waiting times or (3) upgrading to the bigger models that held all components. The second option resulted in the PM partly initiating a hole-shoring strategy: Standard car models were built except for the missing parts and some extra features and would then be completed later on once the lacking component was available again. With this, the OEM could stretch their chip inventory further and somewhat satisfy the demand for new vehicles. However, these cars would then have to be parked and wait for their missing parts indefinitely..

The PM updated the production strategy by allocating scarce chips to optimize their profit for the short term, even though this had negative implications on customer satisfaction. To avoid tensions rising, they used hole shoring to further adapt their production strategy to meet most customer's demands.

iv. Regional Adaptation

A further critical strategic shift of the PM was to change the key performance indicators (KPI) on which the OEM usually based its strategic decisions. To respond to the challenges of the chip crisis, the PM hence re-evaluated the profitability in their operating markets to adjust the regional capabilities of their product offering. Before the shortage of semiconductors, the OEM's objective was to satisfy the diverse needs while also considering the particular demands of the various customers in the planning process of the upcoming production line. Given the new circumstances, they had to focus on new KPIs of their markets: Purchase volume, feature distributions of certain car models, and market-specific legislative requirements. Since the semiconductors were primarily allocated to the luxury car models, PM considered what implications this would have on the areas they were globally running in. With their global representation and significant market share of the premium and luxury cars worldwide (15,5%), the OEM had analyzed sales trends of their operating regions based on the figures per market. They had three core markets: China, Europa, and the USA. Since the OEM was forced to limit their production and had decided to prioritize the production of luxury models, they now had to determine in which markets the products should be rolled out. The decision was based on production volume and feature distribution ratio. Hence an analysis was conducted to understand in which market the highest volume of cars were produced with the most feature distribution. The analysis showed that specific markets sold cars that contained 100% of all (chips-related) features, indicating a clear customer preference to only purchase cars if all features were included. Based on these sales trends, the markets with the highest purchase volume and highest installation rate of features were prioritized for the running production line, as they would be most profitable. Previously five main features had always been included in the OEM's car models: Head-up display (HUD), wide-range light, selective beam, driving assistant and comfort access. Especially HUDs were included in almost all car series they produced. Their highest installation rate of HUDs was in the German market, with only 1,5% of cars sold there without HUD. The PM therefore concluded that the German market was strategically valuable for the OEM and production of cars with HUD should be allocated to this market. The vehicles were therefore first and foremost sent to dealerships in Germany to protect this market and ensure financial stability and gains for the OEM.

Increasingly strict political requirements and country-specific legislation already played an important role before the chip shortage, as they made trade barriers high and impacted the product availability of the OEM in their operating regions. However, this information was now used strategically by the PM to determine in which markets to prioritize for production.

Changes of regulatory requirements were often unforeseeable and short-term and hence considered at a high level of risk for the company. The strategy was further adapted to consider the individual market's requirements by deciding how to allocate production capabilities to certain markets. Given the different rules and regulations the PM determined in which markets it still made most sense to increase their operation in, given the limited chips inventory. Hence legally required vehicle capabilities that require chips were used as a decision factor when considering to which market they should allocate their production. Therefore based on those rules and regulations it was defined in which markets cars should be sold. For this decision, purchasing volume per market was used as a decision factor. Within Europe, the German market dictated clear rules about the head lightening motor vehicles have to possess. This made it clear to the OEM that in such a market all head lightening features had to be delivered, or else they would not be able to sell their cars (with a market share of 33,5% in the German market, this would have left a significant dent in their revenue). After deciding that only luxury SUVs would get the semiconductor used for so-called wide range-lightening (a technology that used a camera selective Beam system that detected oncoming vehicles or those that are overtaking) they decided that a market like Germany, where specific headlight features were 100% required by law would be prioritized in receiving the SUVs with the wide range lights. The Graph below demonstrates the steps the PM implemented in their production strategy on a short term basis:

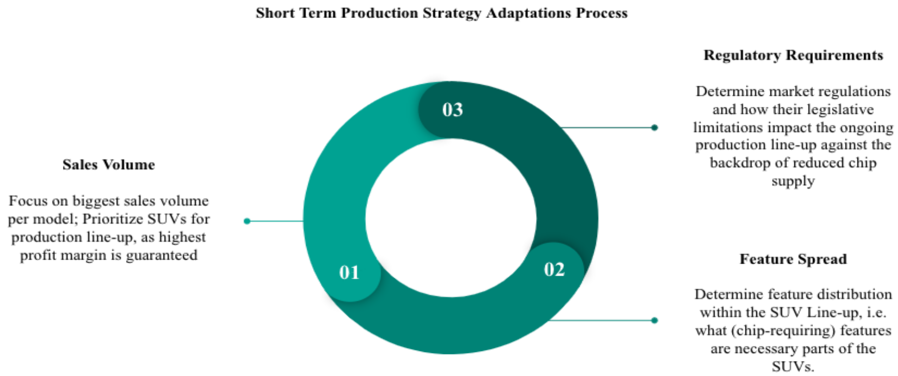


Figure 1: Short Term Production Strategy Adaptation Process

3. Research Note

In the following chapter literature and frameworks in Strategic Planning and Management and Supply chain management (SCM) will be discussed. The aim is to provide a theoretical background on how companies deal with challenges from the external environment in developing their company strategy.

3.1 Competitive Advantage Frameworks

To gain superior profitability, companies aim to have competitive advantage (CA). In strategic management and strategic planning, CA plays a key role whose importance has only been magnified in the literature over the past decades (Barreto, 2010).

Barney (1991) suggests that companies have competitive advantage by employing a strategy that is advantageous to them and is not employed by any other businesses. A company should continue utilizing its existing strategy to gain sustained competitive advantage, while ensuring it cannot be replicated by present or future competitors (Barney, 1991; Baumol et al., 1982). Therefore, a company possesses competitive advantage if it can “create more economic value than the marginal (breakeven) competitor in its product market” (Peteraf & Barney, 2003, p. 314). Firm’s strive to do so by using their own resources and capabilities to maximize the difference between production costs and customer’s willingness to pay (Peteraf & Barney, 2003). However, when resources are fairly distributed and easily transferable, it is challenging for companies to sustain this competitive advantage (Barney 1991).

Therefore, apart from being heterogeneous and hard to transfer, resources must possess all VRIO elements, i.e. valuable, rare, inimitable and the firm possesses the organizational capacity to exploit them for sustained CA (Barney, 1991). Resources are considered to be “stocks of available factors that are owned or controlled by the firm” and capabilities “a firm’s capacity to deploy [those] resources” (Barreto, 2010, p. 258). The Resource-Based View argues that the uniqueness of an organization’s resources and capabilities plays a significant role in determining its competitive advantage (Wernerfelt, 1984). A valuable resource can take advantage of opportunities, eliminate threats and contribute value to the firm, e.g. by lowering manufacturing costs or improving sales (Barney 1991). If a resource is merely valuable and not rare, it can still be used to create “competitive parity” (Barney, 1991, p.107), which does not lead to CA. However, it will produce financial viability (McKelvey, 1982). Rarity refers to the availability of a resource - the less common the resource, the more valuable it is. The third criterion, imitability, considers how easily rivals may copy the resource. Barney (1991) suggests three reasons why resources can be inimitable: unique historical circumstances, causal ambiguity, and social complexity. Social complexity can refer to a firm’s standing with suppliers (Porter, 1980), its (positive) relationships with clients, interpersonal relations between managers etc. Finally, the criteria organization examines the company's potential to derive value from the resource by considering the firm’s “complementary resources” (Barney, 1995, p. 56), such as organizational structures, reporting systems, processes and procedures. Constantly shifting environments regarding technology, demand, regulations and competition challenge companies to maintain sustained CA, as they often lead to unreliable and inaccessible data (Eisenhardt & Bourgeois III, 1988). The concept of RBV was therefore further extended to dynamic capabilities as the RBV proved to be relatively static given “rapidly changing environments” (Teece et al., 1997, p.516) Similar to the RBV, the dynamic capabilities framework considers capabilities to be internal and heterogeneous

Teece et al. (1997) explained firms can reach sustainable competitive advantage if they manage to use these internal capabilities and resources in rapidly and unpredictably changing business environments. DCs are defined as “the firm’s ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments" (Teece et al., 1997, p. 516). The framework focuses on the ability of a company to identify, develop, and deploy its core competencies. Standard operational capabilities reflect the ability of a company to make sure that the current operations and running business are working efficiently. DC on the other hand, are considered higher order capabilities that orchestrate change among a firm’s normal capabilities by allowing a business to focus on creating goods and services that are in great demand (Teece & Leih, 2016). DC’s goal is to ensure organizations are adapting to and changing their business environments in order to create lasting CA (Teece, 2010). They are broken into three main categories: sensing, seizing, and transforming. Sensing includes quickly identifying and evaluating opportunities, risks and developments outside of the firm. This can be achieved e.g. through warning systems and risk management departments that give a firm more time to react to external shocks (Teece & Leih, 2016). Seizing capabilities refer to mobilizing a firm’s resources to seize those strategic opportunities. Several activities are related to seizing, such as identifying new business models and investing in new technology. Lastly, transforming’s key objectives are to ensure a firm’s continuous strategic renewal and the organizational system remaining coherent, consistent and aligned with the company’s strategic vision (Teece, 2020). The DC framework was further developed to emphasize that the speed of the changing environment is essential and also the degree of uncertainty (Teece, 2020). In this context, the main issue for a company’s management in an uncertain environment is deciding what is the right thing to do. Cost efficiency takes a secondary role, as the DC framework puts the priority on deciding “how to do right things” (Teece & Leih, 2016, p. 9) rather than how to do something right.

Barreto's (2010) dynamic capabilities framework builds upon Teece's original framework from 1997 by expanding the scope of the capabilities an organization needs to develop to succeed. Especially in business environments exposed to rapid technological change, the DC framework allows companies to gain and maintain CA by emphasizing internal, strategic competencies and being more resilient when shocks require rapid alignment or expansion.

3.2 Supply Chain Management

“Supply Chain Management is the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers” (Cooper et al., 1997, p. 2)

The business process refers to the flow of goods throughout the entire supply chain, ranging from raw materials and supplies to finalized goods (Tan, 2001). The literature on supply chain management is extensive and follows different paths of definitions of SMC (Grimm et al., 2015). Harland (1996) suggests that SMC can be implemented in four ways: as an internal process for transferring data and goods within a business; in interactions with immediate suppliers; with Tier 1 to Tier n suppliers and customers along the SC, and throughout the entire supply chain. The scope of a supply chain depends on the number of businesses included and their particular roles (Cooper et al., 1997). SMC literature has identified several key features: reliance on production and consumer products, typically viewing SCM as a process, a theoretical structure that mainly utilizes transaction cost economics, and strategies based on gaining a CA (Burgess et al., 2006). Businesses can utilize their suppliers' knowledge, tools, and systems throughout the supply chain to manage their CA (Farley, 1997). By having all key players in the value chain integrate SMC and act together as one unit, the overall performance can be improved (Cooper et al., 1997).

SMC aims to maximize cost efficiency, give businesses and the supply chain CA, decrease inventory, and increase customer satisfaction and value by aligning customer requirements with resources provided by suppliers (Stevens, 1989). Collaboration between several organizations is required for SMC to be successful, both within a firm and across businesses in a supply chain (Cooper et al., 1997). Although traditionally displayed as more of a pipeline, nowadays supply chains are more similar to "uprooted trees" (Cooper et al., 1997). Several factors that influence supply chain management: the amount of available suppliers, raw materials for manufacturers and the complexity of the product (Lambert & Cooper, 2000). The interconnectedness and complexity of today's supply networks has led to a more volatile manufacturing system. In order to stay ahead in the competitive business world, many companies have opted to move their production overseas, which helps to reduce inventory costs and streamline their supply chain while making use of the global market (Lambert & Cooper, 2000). Many industries, such as the automotive industry, aim to simplify the supply chain process by reducing its diversification (Mizgier et al., 2013).

Furthermore, the importance of both RBV and DC in supply chain management research has been recognized (Ketchen et al., 2007). Companies increasingly use supply chains as tools in their strategic management approaches (Hult et al., 2007). The nature of the competitive environment has changed, with firms now competing with one another as components of an entire supply chain rather than just as separate organizations (Ketchen et al., 2007). Hence companies may focus on their core competencies thanks to SMC, which improves their operational effectiveness and competitiveness (Ju et al., 2016). To adapt to the high levels of unpredictability and the continuously changing business environment, organizations must create an agile supply chain by expanding engagement with other supply chain participants (Kim & Lee, 2010). Strong partnerships between supply chain members, which include data exchange and tight strategic collaboration, show a high dedication to success and enable a more responsive SC (Ketchen et al., 2007). Hence, organizations should develop their supply chain DCs to quickly adapt their supply chain operations to stay ahead of the competition and maintain their long-term financial success (Allred et al., 2011).

3.3 Bullwhip Effect

In the field of SMC the bullwhip effect (BE) plays a key role: The synchronization of supply and demand along the supply chain is strongly affected by the BE. The first academic explanation of the BE was provided by Forrester (1961), who demonstrated that a supply chain is afflicted by huge fluctuations of demand, especially when firms along the chain decide to tackle issues individually. Later a detailed definition was given: "*If demand for products is transmitted along a series of inventories using stock control ordering, then demand variations will increase at each transfer*" (Burbidge, 1984). The BE therefore describes how the order variability increases the further up the supply chain one moves (Lee et al., 1997). When consumer demand changes (either slowing down or increasing) it will result in large fluctuations in the production process of suppliers along the supply chain (Wang & Disney, 2016). If the companies along the supply chain then decide to react individually to these elevated swings in demand, the discrepancy between demand and supply will only increase and be carried along the supply chain affecting all firms along the way (Forrester, 1961).

The literature provides two schools of thinking on the BE: system thinking and operations management (Miragliotta, 2006). System thinking refers to the systematic background of supply chains and how complex and not well-understood systems can lead to the BE. The operations management school refers to individual factors and singular effects causing BE (Miragliotta, 2006). Furthermore, four leading causes of the BE have been identified: Demand processing, Order batching, Price fluctuations and rationing and shortage gaming (Lee et al., 1997). Firstly, demand processing's key objective is that misinformation quickly travels along the supply chain. This misinformation often comes from using past demand information to forecast future demand patterns. The misinformation gets even more amplified if long lead times in production are in place, as longer lead times lead to higher set inventory levels. Secondly, order batching refers to firm's aiming for discounts by ordering larger batches at once and having more inventory at hand. Thirdly, price fluctuations lead to upstream companies quickly building up their inventory stock (Lee et al., 1997). As a consequence, they then only place further orders in the next period, as they are already stocked up, which leads to a disruption of a steady demand pattern. Finally, rationing and shortage gaming focuses on how manufacturers need help understanding what the actual demand along the supply chain is (Lee et al., 1997). Given that demand is greater than the manufacturer's production capacity, they will start rationizing their products depending on the customer's ordering size. If firms recognize this rationing along the supply chain they will increase their orders to achieve their desired amount of products (Lee et al., 1997). However these orders are often canceled later, leaving the manufacturer with a huge order quantity (Lee et al., 1997).

4. Teaching Note

This chapter offers guidance and assistance to instructors or professors when teaching the case study. It includes suggested questions, answer guides to the questions and a proposed approach to teaching.

4.1 Teaching Objective

The objective of the case study is for students to evaluate how a company changed its competitive strategy in response to a crisis. The case scope is not limited to dealing with a crisis: The students should learn how a) different factors can affect a company's CA and b) strategic concepts can aid companies in overcoming challenges. This case primarily focuses on using dynamic capabilities for strategic decision management. This case is based on a real-life example of an automotive company in the premium and luxury segment. As a decision-based case, students are asked to play the role of the product management team of the company, analyze the situation described, and form production strategy recommendations.

4.2 Teaching Audience

The case study is recommended for undergraduate and postgraduate students in the fields of Management, Economics and Business Administration. Even though there is a partial focus on the topic of supply chain management, the case study should still be mainly used for strategic management courses, as it aims at demonstrating how companies use dynamic capabilities to make strategic management decisions.

4.3 Teaching Approach

The case study is designed to help students apply theoretical frameworks they learned to real-life cases. The frameworks outlined in the research note chapter should be taught beforehand to allow students to apply this knowledge practically. Provided that the theoretical knowledge is taught in previous lessons, a two-lesson approach is recommended for the case study.

Lesson 1: The interactive "Beer Distribution Game" gives students a hands-on opportunity to study the Bullwhip Effect[11]. Students play a game in which they learn how poor communication and unpredictable ordering can disrupt the supply chain. They are separated into four groups: Retailer, Wholesaler, Distributor, and Factory. After the game, the students evaluate the outcomes, debate their consequences and then brainstorm to identify what dynamic capabilities are necessary for companies to successfully manage crises.

Lesson 2: Case Study Discussions
Students are advised to read the case before the lesson, as they will be divided into groups and discuss and present the recommended questions. Following structure is recommended:

Step	Activity	Time
(1) Setting the stage	Getting all important facts on the case[12]	5 Minutes
(2) Define Problem	Identify the issue[13]	5 Minutes
(3) Group work on Questions	Divide students into groups of 4-5 students (form roughly 5 groups). Each group will answer one question. Each group will also be assigned another group to ask questions and vica versa to encourage student discussion	30 Minutes
(4) Presentation & Discussion	Groups will present their findings and answers. Their assigned group will start with questions they prepared and other groups are also welcome to join in on the discussion	50 Minutes (Presentation should be 3-5 Minutes and

[11] See Appendix for detailed class description
[12] See Appendix for suggested questions to obtain all information
[13] ibid

		then discussion 5 Minutes)

Following Questions are assigned to the case study:

1. Assess the OEM's dynamic capabilities
    a. to sense opportunities and threats
    b. to make timely and market-oriented decisions
    c. to change its resource base
2. How did the BE affect the OEMs product strategy and comment on how this can be addressed?
3. Should the OEM change how they deal with their suppliers and if so why and how?
    a. Do you recommend that the OEM changes from JIT processing to JIC? Explain your answer
4. Analyze the strategy changes the PM implemented
    a. In terms of their supply chain management
    b. How does this support the OEM to prevent future shortages?

4.4 Discussion

1. Assess the OEM's dynamic capabilities

- **a. to sense opportunities and threats**
- **b. to make timely and market-oriented decisions**
- **c. to change its resource base**

The question is based on the dynamic capability definition of Barreto (2010):

"*A dynamic capability is the firm's potential to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base*"

It is assumed that students understand dynamic capabilities and the important role they play in a company's competitiveness. To address the questions, it is expected that the different types of resources are known: Tangible (financial and physical), intangible (technology and reputation) and human resources. For the following questions students should identify and analyze the changes the OEM implemented in its strategy to retain its competitive advantage.

a) To sense opportunities and threats

The OEM's operations is heavily influenced by their customer's behavior, rapidly evolving technology and shifting market dynamics. The student should consider how the company's size and worldwide presence affects its adaptability and capacity to provide agile and ad hoc strategy changes. For successful strategic planning, the OEM must recognize opportunities and threats within the automotive industry and utilize its capabilities to attain competitive advantage.

From the case study, the student should refer to the geographical distribution of the OEM: Having established a strong sales network in 135+ countries allowed them to gain significant insights into the markets and trends that could shape their strategy in the future. They are constantly monitoring their key markets and analyzing movements and trends to identify opportunities in their competitive environment. The OEM uses a proactive approach, conducting extensive research to ensure they stay on the cutting edge of car manufacturing. Combined with close monitoring of key business processes and strict cost control, it has enabled the company to guarantee profitability and return on capital, even amid the chip crisis. This allowed the company to identify immediate and long-term opportunities to modify its production strategy, e.g. regional market adaptation and vehicle-specific changes.

Furthermore, a centralized risk management department exists to manage threats. Internal control mechanisms are added to this on a team-by-team basis to carry out risk control within the OEM. Using a loss distribution mechanism, the severity of risks is often assessed for a period of 12 to 24 months. Even though such a risk management department exists and they are continuously monitoring markets and trends it was difficult for the OEM to anticipate the chip shortage. The OEM's strong capability to sense opportunities in the given market climate and come up with tailored short-term solutions, such as focusing on luxury SUVs, proved to be a rather reactive modification of the production strategy in response to the chip shortage. This demonstrates that its capabilities to sense threats must be improved to be able to anticipate similar problems in advance and respond quickly.

b) To make timely and market-oriented decisions

For this question, students should consider the OEM's ability to quickly and effectively respond to the changes in the market caused by the chip shortage after having previously identified opportunities and threats. Several aspects should be considered in this regard: The strong market position and brand image that the OEM had built up over the years as a leading high quality car manufacturer in the premium and luxury segment gave the OEM some agility in their decision making process. They exploited their strong reputation and customer's loyalty to shift their production focus to luxury SUVs and almost completely stopped making all other cars to assign the available chips to the SUVs.

Furthermore, their market monitoring capabilities allowed the PM to understand their customers' needs and enabled them to accurately target the right markets to expand their limited production. As the chip shortage continued, the PM had to respond quickly by prioritizing specific markets and customer groups. The OEM uses advanced data analytics to understand consumer behavior and markets with the highest profitability potential under the circumstances. Gaining this data from market analysis and constant exchange with their key market regions, the OEM was able to focus on the best target market given the limited production capabilities. Understanding the trends and current market movements lead to a range of their products and services being reviewed and adjusted. The PM understood the timely need for a revised product due to the chip shortage and hence had to innovate how they processed their cars normally, using their market knowledge. Furthermore, brand reputation (as an intangible asset) gave the OEM the capacity to create value for themselves.

c) To change its resource base

Changing a resource base refers to reorganizing and optimizing the resources a company already has at its disposal to produce more economic value with the same materials. Given the challenges the chip shortage posed for the OEM, they partly re-utilized and adjusted their resources to meet these issues. Firstly, they reallocated most existing resources & capabilities to identify ways to restructure the manufacturing process to boost productivity and reduce the amount of semiconductors needed. This included reconfiguring their production process to focus on luxury models and reconfiguring the required components for smaller car models. Secondly, as mentioned in the case study the OEM engaged in new strategic collaborations to improve the efficiency of their supplier relations. On the one hand this enables the OEM to secure required chips in a more timely and steady manner and avoid delays or production stops. On the other hand it introduces the sharing of current production and order information between the suppliers and the OEM helps them prepare more proactively for shortages in the future. Thirdly, the OEM invested heavily in R&D to foster innovation and find a way to better integrate software in their assembly process in order to reduce the amount of semiconductors needed.

Overall the efforts of the OEM to use its DCs to reconfigure resources & capabilities, sense threats and opportunities as well as make market-oriented decisions were successful. However despite the success, there is still much room for improvement, as the OEM heavily relies on third-party suppliers in the Asian market, needs to diversify its supplier network and enhance its in-house technology in order to ensure its long-term success in the automotive industry.

2. How did the BE (bullwhip effect) affect the OEM's product strategy and comment on how this can be addressed in the future?

Students should have a basic knowledge of the bullwhip effect, its causes and potential solutions to mitigate its consequences. In light of the fluctuating consumer demand for new vehicles in 2020 students should analyze the impact of the BE on the production strategy and new capabilities the OEM created to deal with this issue in the future.

A consequence of the BE was distorted information on consumer demand along the supply chain. Therefore the OEM not only had difficulties forecasting the order patterns of manufacturers, foundries, Tier 1 suppliers along the supply chain, but also their customer's demand. The BE affected the OEM's production strategy in the three measures: (1) Low inventory of chips led to inability to produce all requested vehicles, changing the OEM's production capabilities (2) A strategic prioritization on luxury vehicles was introduced, whilst narrowing their target group and re-allocating resources to markets, where the feature distribution and requirements were most in demand. (3) Weak points along the supply chain process of the OEM were identified, prompting them to increase the number of suppliers they work with to increase inventory availability.

To effectively prepare its strategy to face future challenges, the OEM should analyze and utilize their capabilities and opportunities to turn them into sustained competitive advantage. The student should refer to potential capabilities and resources that the OEM could develop based on the information provided in the case study (two examples below):

(1) **Share Information and IT Capabilities along the supply chain:** Working in close partnership with Tier 2, Tier 3, and other suppliers in the supply chain, valuable data on consumer demand and production capacity can be shared and accessed, technological knowledge exchanged and chip inventory ensured. This enables the

OEM to anticipate inventory shortages more accurately and rapidly adjust its production in response to changes in demand and chip availability. To gain value from this it is vital that the information not only gets shared by the OEM, but that they also receive the necessary data from their Tier 1- Tier n suppliers. By sharing short- and long-term forecasts with suppliers, the OEM allows the suppliers to determine their production and inventory capacity and identify constraints early on, which will benefit the OEM.

(2) **Expanding Technology Capabilities.** Increasing the synergy between hardware and software and developing the ability to overwrite and adapt the software on certain chips is recommended. By expanding its technology and especially software capabilities, the OEM can protect itself from low inventory and the dependency on certain chip types and quickly adapt and adjust to a change in production capacity of manufacturers. Being able to overwrite the software would allow them to easily switch to other chips and suppliers and not have to wait on the production of one chip category, while only using a low amount for their running production.

In the last step, the students should then determine if these capabilities can be a source of sustained competitive advantage via the VRIO framework:

Resource or Capability	V Valuable	R Rare	I Inimitable	O Organization	Impact on Competitive Advantage
IT & Information exchange process	✓	✓	✗	✓	Temporary competitive advantage
Expansion of technology and synergy of hardware and software	✓	✓	✓	✓	Sustained competitive advantage

Figure 2: VRIO Analysis of two key capabilities

3. Should the OEM change how they work with their suppliers and if so why and how?

This question aims to understand the OEM's relationship with its suppliers and its resulting consequences on the production strategy. Given its size and global distribution, the OEM is normally considered a "big player" in its supply chain and (especially) the Tier 1 suppliers are aware of the importance of maintaining a good working relationship. However, for chip manufacturers, only 7% of their business comes from the automotive industry. As a result, the automotive industry's demand represents a sizable, but not an overwhelmingly significant component of their business[14]. The chip shortage demonstrated big pain points in the automotive-semiconductor supply chain, greatly affecting the OEM's production strategy. Two main factors were: Dependency on factories in the Asian market and highly optimized supply chains with a main focus on cost efficiency (above all).

By adapting their working processes with the suppliers, the OEM can attempt to use its existing resources in a new way to create value for the future:

(1) **Managing supplier risks**: To increase the ability to manage risks in a multi-level supplier network proactively and identify them on a real-time basis, the OEM partly extended its risk monitoring capability by attempting to collaborate more closely with suppliers. Disruptions to the supply chain can be caused by external events, suppliers and geographical tension. By detecting them early on, the OEM will be able to adjust its production strategy more swiftly. This means that working with their suppliers will be changed to create greater visibility on the supply chain.

(2) **Expansion of supplier network:** Collaborating more closely also with Tier 2 and Tier 3 suppliers the OEM gains insights into their work processes. That way they can aim at operating according to a synchronized demand pattern along the entire supply chain, whilst getting visibility on key metrics, such as lead times, production capacity and more.

(3) **Vertical integration of suppliers and manufacturers:** This can be achieved by considering an extension of their business to producing their own software for the chips, but letting this be produced by actual manufacturers, such as Samsung.

Changing these resources will provide a positive long-term effect on their production strategy and their competitive advantage. The value of these changes can be analyzed by the student using the VRIO Framework.

[14] Graphs to demonstrate semiconductor business environment and dependencies can be found in the Appendix

Resource of Capability	V Valuable	R Rare	I Inimitable	O Organization	Impact on Competitive Advantage
Supplier risk management systems	✓	✓	✓	✓	**sustained competitive advantage**
Supplier relations (expansion)	✓	✓	✗	✓	temporary competitive advantage
Process alignment (vertical)	✓	✓	✓	✓	**sustained competitive advantage**

Figure 3: VRIO Analysis Question 3

3a. Do you recommend that the OEM changes from JIT processing to JIC? Explain your answer

To answer this question, prior knowledge of the mechanisms of just-in-time processing and just-in-case is needed. Depending on the course structure, students are expected to have this knowledge from previous courses or provided by the instructor. Just-in-time processing is the traditional method that the PM applies for their production system. Against the backdrop of cost-efficient global sourcing and reducing production costs, just-in-time processing allows the OEM to produce at a very high level with low storage and inventory costs. No materials are kept in the warehouse as reserves, because they are used as soon as they are received. This further increases the flexibility and agility of the OEM's supply chain. One major weakness however is that with external factors, such as a shortage of raw materials, production stops due to lockdowns or natural disasters, the JIT leaves companies very quickly without their needed supplies. On the other hand, just in case strategy is especially useful in times of uncertainty as it provides a support cushion for companies. This gives them sufficient response time to reconfigure their production processes and still be able to deliver products. However, it leaves a company with wasted materials and higher storage costs when consumer demand decreases.

In the case of the OEM, given the size and complexity of supply chains and global distribution and sales network, it is impossible to single out one of the two processing options as the best practice. Competitive Advantage through cost efficiency is sought after by car producers, but the shortage has shown that a certain amount of inventory is recommended. In times of crisis, having an inventory to fall back on gives the OEM the luxury and flexibility to focus its production strategy on differentiating their products to overcome any issues rather than having to focus on inventory and cost factors. The student should analyze if for the OEM it is more cost-effective to hold onto supplies for increased production volume or if they should face the danger of running out. A hybrid model between JIT and JIC can allow the OEM to reap the advantages of both systems: keep an inventory to respond quickly to disruptions in the supply chain and try to push their costs down by ordering in time for the assembly. Additionally, the OEM and suppliers can establish a "fixed + variable amount" system: This means that from certain suppliers the OEM will always get a fixed amount of chips, e.g. 10000, and have a variable amount additionally, e.g. +/- 5000 pieces to be able to respond to demand increase or decrease.

To summarize neither only one or the other options is the best practice for the OEM. Given the nature of the automotive industry with rapidly changing technology, changing consumer demand and complex supply chain systems the OEM needs to both be able to react quickly, by stocking up on inventory and also stay competitive by producing cost efficiently.

4.Analyze the strategy changes the PM implemented

a. **In terms of their supply chain management**
b. **How does this support the OEM to prevent future shortages?**

The question aims at understanding the PM's changes to the production strategy to support the business during the chip shortage. To analyze the strategy adjustments, the students should rely on their knowledge of competitive advantage, supply chain management and the information given in the case.

(a) In terms of their supply chain management

Students should target the core characteristics and issues of the automotive-semiconductor supply chain, by referring to the information in the case study chapter. To support their findings, they should rely on and analyze further the literature on supply chain management and especially how issues, such as bottlenecks, can be tackled. The case shows that the PM's strategy changes focused mainly on internal capabilities and how they can be adapted - on a short-term basis - for the production. One of the more long-term changes that affected the SMC of the company was the expansion of their supplier network to secondary battery producers that were located closer to their factories. This indicates a step in the right direction with the strategy adaptation leading to more flexibility in terms of chip inventory. However there is still more room for improvement, as geographical dependencies and intense competition for chips are impacting the efficiency of the OEM's supply chain and hence their profitability.

(b) How does this support the OEM to prevent future shortages?

The case study indicates that certain learnings that can be drawn from the strategy that will aid the OEM in the future when dealing with the same or similar crisis: On the one hand flaws within their optimization of the supply chain became more visible that indicated a necessary change. Diversifying their chip portfolio by engaging with other suppliers and hence moving away from solely working with producers in the Asian market will create a certain inventory buffer for the OEM to fall back on. Re-assessing their communication mechanisms with the companies along the chain to proactively receive and share data will allow the OEM to plan its purchase and meet customer demand accurately. Furthermore, the students should mention how the strategy change opened the OEM up to new opportunities to further develop their capabilities for the future. Regional Adaptation allowed the OEM to maximize their local responsiveness and focus on the strengths of their markets. This is also an important insight for the OEM to further investigate and develop to expand on localized target groups and their requirements. This knowledge that was gained can be strategically implemented when considering expanding the sales network even more. Furthermore students can mention how the strategy changes of the PM opened the path for the OEM to expand its technology capabilities even further: The chip shortage demonstrated that given the trends of the automotive industry and that semiconductors will stay an important part cars, there is a lot of room of development left in the area of centralized software development of car components. Instead of having numerous electronic control units scattered throughout the vehicle, they can use their knowledge to reduce the complexity of semiconductor softwares in a car by unifying them in a centralized computer. Further options in the development of technology capabilities can be mentioned by the students, indicating how these learnings from the strategy change can aid the OEM prepare for the future.

5. Limitations

When analyzing the case study some limitations have to be considered. Due to the fact that the chip crisis is still ongoing, the data referred to is based on the years of 2020 and 2021, as the data for 2022 could not yet be obtained. OEMs are currently still dealing with the shortage and adjusting their strategies in order to remain competitive. In-depth data on this topic is therefore scarce and dealt with very sensitively and the OEM's were restricted in providing any company specific information to outside sources, to avoid this information being used by their competition. As previously stated the numerical data in the case was based on the actual numbers of the OEM, but had been adjusted to avoid data being tracked back to the company.
Further research of the role of dynamic capacities in strategy adaptation in response to the chip crisis should be conducted with a more thorough, detailed case study, in order to overcome some of these constraints. Furthermore restrictions are also placed on the study's reach in terms of the scale of the OEM due to the nature of the research methodology.

6. Conclusion

The semiconductor shortage, which has been plaguing the automotive industry since 2020, has had a significant impact on the production of cars. Nonetheless, the OEM was very quick to respond once the consequences of the shortage started to unfold in 2020. Their strategy adjustments took place on four levels: short-term, long-term, strategic and operational. These adjustments were based on the capabilities that the OEM had built up over the years and were implemented considering the areas they can influence without having to fall back on third parties. Their short-term adaptations (Vehicle-specific adaptation and regional/legislative adaptations) resulted in ideal resource allocation whilst still maximizing their profit and trying to maintain customer satisfaction. They managed to keep their competitive advantage and remain profitable with their swift move to focus on luxury vehicles. However, the measures taken were of a reactive and short term nature, indicating that a deeper restructuring of their production strategy roadmap is vital to remain competitive in the future. Whilst they were able to carry the OEM through the beginning of the chip crisis, the fact that still in 2022 the shortage has not been solved led the OEM to also execute long term adjustments: Expansion of R&D capacity and supplier network.
The chip crisis made one thing very clear for every OEM: They cannot avoid something that they do not see coming and hence action must be taken. It prompted the OEM to reevaluate

its internal processes and capabilities in regards to its production strategy as well as key issues of its supply chain. The crisis highlighted three main areas that need the OEM's focus to retain their competitiveness in the future:

(1) Shifting away from "traditional" manufacturing to more technological and software based product development and production
(2) Targeting key underlying issues of the semiconductor supplier network
(3) Using advanced technology and exchanging key information along the supply chain to enhance risk management and forecasting of orders.

Semiconductors will remain a key component for many industries with their importance skyrocketing day by day. The limited availability of chips could inhibit the production of anything depending on them, because there are no other viable alternatives and expanding production would be time-consuming and expensive. Under these circumstances the OEM needs to shift away from traditional and simple car manufacturing to more software and technology based manufacturing. The technology used by the automotive industry is comparably "old-fashioned" when considering how other industries have evolved, also in regards to the usage of semiconductors. The automotive environment is already changing with companies such as Tesla disrupting the traditional structures moving cars to becoming more electrically and software engineered products. Creating synergies between hardware and software as a core basis of their production development and production processes is a future business model the OEM needs to integrate in their existing mechanisms.

With the business environment rapidly changing given the evolving technology there are new challenges ahead that the OEM needs to prepare for. The biggest internal change the OEM is facing is to be able to anticipate those challenges and also utilize opportunities more proactively and early on to position themselves more strongly in the future. The crisis created an opportunity for the OEM to rebuild the rules and framework for their supplier relations, by establishing direct contractual agreements with suppliers further up the supply chain, procuring and sharing more on-time data and aligning demand patterns within the supply network. To reach these strategic goals the OEM needs to assess its priorities of its future production roadmap and in this course assign the needed resources and investments to acquire new skills and capabilities.

It is clear that going forward the OEM is not only competing with other OEMs but also with other industries for critical part supplies such as semiconductors. With a clear focus on improving collaboration and data transparency along the entire supply chain and significantly building up its IT and software engineering capabilities and resources, the OEM is strongly positioned to improve its competitive advantage.

7. Appendix

Appendix A: Interview Transcripts

Given the confidential nature of the company's strategies regarding the chip shortage, the thesis was anonymized and the interview transcripts and content were also anonymized to protect the company. Thus, the following transcript provides a summary of the main points obtained from the interviews (translated from German and written in answer format for most questions) as well as the interview guide.

Table 3: Product Management Team/Team Lead Interview Guide

Introduction:
 	
Hello and welcome to the interview!
 	
Thank you for taking your time to meet with me. The interview will take roughly 45 minutes. In the course of my Master Studies at Católica Lisbon University I am writing my thesis on how a car manufacturer has to adapt its strategy facing the chip crisis. The case study will be set in a strategic management framework based on my master course: Management with specialization in strategy, entrepreneurship and impact.
 	
Introductory Questions & Getting to know the company
 	
1. What is your position at your current job?
2. Please describe the daily processes of your team
    a. What other teams do you work with?
    b. Who are key internal and external stakeholders?
3. Please describe your current production strategy
    a. How do you deal with production issues?
    b. What are key elements you focus on for your strategy?
4. What processes do you have in order to monitor and identify threats and opportunities?

5. What are the company's plans regarding its future growth?
6. What are the key success factors in the automotive industry at the moment and do you believe your company is achieving them?

Chip crisis and strategy changes?

1. How has the chip shortage affected the automotive industry?
2. What was happening in your production process for you to change your strategy?
    a. How was your competitive environment impacted? Can you give some examples?
    b. What changes did you detect in your markets and customers' purchasing behavior?
3. What was your goal in modifying your strategy?
4. How did you have to adapt your production strategy in the wake of chip shortage?
5. How did you determine what aspects needed to be changed in your strategy?
6. Describe the impact this strategy has had so far?
    a. What benefits have you realized?
    b. What challenges?
7. Do you think that with your new strategy your competitive advantage has been improved and why?
8. Was your company able to improve during this crisis and why do you think they were able to do so?
9. Looking back: how has the strategy change impacted the profitability of your company?

Table 4: Outline Answers from Product Management Interviews

Question	Overview Answers (summarized)
Please describe the daily processes of your team	The team works at the interface between sales, which are customers that buy cars and the markets we are operating in and vehicle development, which covers all teams that

	take care of the technology part. Working together with both sides is very important: We have daily meetings with our key markets that give us updates and market analysis on the current state of the market, so for example what features are currently trending in the market. On the other hand vehicle development is another important team that we are working closely together with: they understand if changes in the production are technically feasible or if the solution we propose does not work. As product management we need to understand our client's requirements, e.g. they need larger displays or customers want softer seats. There are two production processes that we are looking at: planning the production for next 5-10 years and supporting the current vehicle production line up. Our work consists of market analysis, data analysis and managing both the customer and production side of the car assembly process
How do you deal with production issues?	We have two different ways of dealing with issues in our production line. The first one is called an "orderly process". For example special equipment was blocked as head up displays could no longer be ordered for the German market. We normally get this information from the purchasing unit at our company and then we discuss this with our markets and try to work out how to change this for the coming production line. The second process is called the "emergency process". This is implemented when we have to react, e.g. within a week, because we are for example not getting anything from our suppliers anymore. We then "stamp" the

	production of certain cars. In the factory they will then receive the message that a certain model has been "stamped" so that means something will be missing in its assembly and we have to manufacture it with holes. It's important here to note the technical dependency, we can only build cars with missing components if vehicle developments gives us the green light that we can later on include the parts again.
What processes do you have in order to monitor and identify threats and opportunities?	There's an overboarding process, hence a risk management department that is generally in charge of determining and finding first hand solutions for risks. Also each team and department has their own process to detect risks in relation to the work they are doing. We work closely together with our markets and from that information we can understand what current trends are, e.g. if in the Chinese market all the clients now want head up displays, we know to include this in the next production line and see this opportunity.
What are the company's plans regarding its future growth?	One major goal for us is to expand our production to BEV car models. We set the goal of offering a complete array of BEVs by 2030 and continuously expand our R&D capacity and production plants. We realize that there are major trends in the automotive industry and we want to be at the front, which is why we want to build more electric vehicles in the future.
What are the key success factors in the automotive industry at the moment and do you believe your company is achieving them?	There are several factors that automotive manufacturers need to manage, such as the complexity in technology, production, and supply chains. These are all very critical for car companies to remain competitive. Developing vehicles that stand out from the competition is key, which is made difficult by the sheer number of possible

	configurations. The top trends in the automotive industry are digitalization, electrification, autonomous driving, and sustainability, all of which must be taken into consideration when creating new vehicles.
How has the chip shortage affected the automotive industry?	The chip shortage showed how dependent we have become on a highly optimized global supply chain and how fragile this supply chain really is. In the last decades we have highly optimized our supply chain not only for just in time delivery, but also for just in sequence delivery, which reduces storage and warehousing costs. This also includes global sourcing, i.e. outsourcing production processes to reduce costs. With the onset of the coronavirus pandemic, lockdowns in certain regions and natural disasters have further overstimulated the system, leading to suppliers being unable to deliver on time. This has been compounded by an already functioning system that was near its capacity limit.
What was happening in your production process for you to change your strategy?	We got the message from our purchasing unit that suppliers were not able to deliver semiconductor chips anymore or only very little supply of chips. The purchasing unit tried getting the chips in different ways, but in the end we had to deal with a lot less chips than were normally needed for our production. So what was happening was that all of a sudden we only had a certain amount of chips left that will only get us through roughly 6-7 weeks if we want to use them for every car that we are producing.
What changes did you detect in your markets and customers' purchasing	Generally speaking it is visible that the competition between companies in the automotive industry and consumer electronic sector has become more intense.

behavior?	Previously, one supplier supplied both Samsung and our company, which wasn't too bad until supplies began to dwindle. Then we could feel the shock of the supply decrease. There was an obvious decrease of demand for new cars from our customers in the beginning of 2020, that we felt. . Even though our clients quickly accepted that we couldn't provide all cars, they did have some issues, such as not being able to install wireless charging trays or configure new cars according to their preferences due to the chip crisis. As a result, 46% of orders had to be changed.
How was the competitive environment impacted?	The competition in the industrial and consumer electronic industry has become more visible and somewhat more intense. We have mostly served as an OEM for small customers, which has caused us to fall into the background. Previously, we were also in competition, but it was less of a problem while one supplier supplied for example both Samsung and our company. The problem was then when they weren't able to supply both of us as again our company then fell short.
What was your goal in modifying your strategy?	Without chips that could be used for the entire production we knew that we quickly had to find a solution and change our production strategy so that at least some vehicles can still be produced. The goal was at first to survive and be able to somewhat satisfy the demand for cars. The second goal was definitely motivated by financial stability, so to be able to keep producing and keep selling cars. These were mainly quick fixes of our strategy, but in the long term the company has more elaborate goals: we want to become less dependent on certain chips. We want to continue to improve our in-house technology and the technology used in the cars. There's a lot happening in the

	automotive industry at the moment and apart from semiconductors we have to be able to meet the needs of our clients and also deal with the technological challenges that are occurring.
How did you have to adapt your production strategy in the wake of chip shortage?	Specifically for the production process we changed the strategy in two aspects. The first one is more of a regional control. That means we had to decide what regional markets we need to "protect". We knew that for example in Germany special equipment lights needed to be installed in the cars or else we could not sell them. So then we knew that this was definitely a market we needed to protect. We also determined here how big the production volume per market was to understand which markets had the highest take rate. The second aspect was the vehicle specific control, where we decided to protect the cars that make the most money. Those were our luxury SUV products, as these created higher revenue for us.
How did you determine what aspects of your normal strategy needed to be changed?	Most of the time and also in this case with the chip shortage the aspects we need to consider is our financial stability. To decide what aspects needed to be changed we had to ask ourselves the following questions: Where do we earn the most money concerning cars?(e.g. the big SUV will give a higher profit than our 2 door car); in which markets do we earn the most money); In which markets do we have special customer requirements, from a customer strategic point of view?And in which markets do we have to offer, e.g. a head up display because the car is only approved with display. We tried answering these questions and then determined what aspects we had to change
Describe the impact this strategy has had so far? What	We could definitely see that our numbers were not going down even though there is a chip shortage - this was

benefits have you realized and what challenges?	definitely a major benefit for us and only supported us in our decision to focus e.g. only on the SUVs mainly at first. This is of course challenging, because this cannot be the long term solution to the problems with semiconductors, but for the moment we got great benefits from it.
Do you think that with your new strategy your competitive advantage has improved and why?	In parts, cutbacks had to be made because top features were missing (e.g.wide-range light, wireless charging), but generally the strategy change allowed us to quickly find a solution and still have successful 2020 and 2021 concerning sales. Our advantage has always been that we sell high quality products and this has not changed, we had to narrow down what products we are selling - we focused on our luxury SUVs - but they were still up to the standard we delivered before the chip crisis. The competitive advantage has been partly improved, we definitely have made the most of our assets to be able to sell cars, even though we didn't have all the needed chips for it. But still we need to consider that those were more quick solutions and that the long term solutions we have started, e.g. more investment in R&D, are the ones we need to monitor in the future to see their impact on the competitive advantage.
How quickly were you able to turn this information into action?	Normally, if a decision is made to implement new rules in the factories, they will need to be approved by a decision-making body before they can be put into action. This process may take some time, although if the situation requires it, it can be done more quickly. In the case of the chip shortage, we were able to respond very quickly to the given circumstances.

Table 5: Industry Expert Interview Guide

Introduction: Hello and welcome to the interview! Thank you for taking your time to meet with me. The interview will take roughly 45 minutes. In the course of my Master Studies at Católica Lisbon University I am writing my thesis on how a car manufacturer has to adapt its strategy facing the chip crisis. The case study will be set in a strategic management framework based on my master course: Management with specialization in strategy, entrepreneurship and impact. Introductory Questions: 1. What is your current position at your company? 2. Where do you get your chips from and how do you use them in your production process? 3. What are some of the major challenges vehicle manufacturers have been experiencing due to the chip shortage? 4. How has your production strategy been impacted by the chip crisis? 5. How has your company been strategically dealing with the chip shortage in terms of its production? 6. What are some of the successful strategies that companies have implemented to overcome these challenges? 7. Did the industry meet the anticipated goals, and if not, what could have been altered to produce better results? Strategy of the OEM: 1. Do you believe that this strategy is effective to prepare companies for the Chip Crisis? Why?

2. Do you believe this strategy to be beneficial for a different crisis or just the chip shortage? Why?
3. Do you believe this provides a competitive advantage compared to what other companies are currently doing? If yes, to what extent?

Table 6: Outline Answers Industry Expert Interview

Question	Overview Answers (summarized)
Where do you get your chips from and how do you use them in your production process?	We work together with one big chip supplier and have actually developed a chip ourselves. So that's then used as the one main chip that controls the software of all the small chips that we later integrate in the car. We did not build the chip ourselves, but we developed the software for it and then had the chip supplier create it.
What are some of the major challenges vehicle manufacturers have been experiencing due to the chip shortage?	Firstly, you have to understand how important chips are to automobile manufacturers: there are a lot of chips in the car, but there is no centrally controlled computer that controls that. You need a chip for everything, e.g. that the car seat automatically moves forward and backward. The problem for other car manufacturers is that the chips come from different manufacturers / suppliers and each supplier has its own software and chip that they produce. Then when a chip is suddenly missing or just not being produced and supplied anymore the car manufacturers face a huge problem: how can we continue producing if we are missing essential components for the car? I think that is the main challenge that manufacturers have,

	having to re-think on how they can produce cars, meet demand and get the best revenue whilst operating with only part of the necessary chips.
How has your production strategy been impacted by the chip crisis?	The sales of our company have of course been affected somewhat by the chip shortage, we also have not been completely spared by this. There definitely were supply bottlenecks, but we have always ordered quite aggressively and have built up a chip inventory. We have always expected rapid growth for our company so we always had big orders of chips. But we did have to look for other suppliers as well. As I already mentioned, the advantage we then had compared to other car producers is that we can work with any kind of chip - and this is definitely not the case for all car producers. so we bought chips from any supplier possible and if needed customized the software on site
How has your company been strategically dealing with the chip shortage in terms of its production?	Our company differs from the traditional car manufacturer. We have a computer that controls everything centrally. So that means that in our cars there is one centralized unit or computer that controls all the chips that are within our cars. The software for this is written by ourselves and we can therefore install other or different chips. They may need a software change in order to work in our car, but that is done within our company, so we are not dependent on getting exactly the right chip, but we were able to change to different and some cases just more available chips and then we just had to adapt the software on the chip so its linked with our central computer. That's the key difference of our cars: we combine software and hardware together, whereas most of the big car manufacturers do not think of hardware and software

	together, they see it as different parts. Traditionally car manufacturers focus on assembling a car with different parts as cheap as possible. We focus on the software and integrating software and hardware together, similar to how Apple does it. So as far as the strategy goes we did not have major changes, but because we already from the beginning build the cars differently or let's say with more focus on the software we were able to find suppliers that could provide not the "traditional" chips, but ones that we were able to overwrite with our own software and still use.
What are some of the successful strategies that companies have implemented to overcome these challenges?	OEMs have started to focus on cars with high profit margins and taking advantage of their established position in the market. For example our company disrupted this model, as they started to aggressively buy chips, needing fewer components than our competitors and being able to switch to other chips faster, allowing us to continue to innovate our technology and keep producing
Did the industry meet the anticipated goals, and if not, what could have been altered to produce better results?	The chip crisis has hit all industries pretty hard and the automotive industry was a very prominent example. A lot of firms were concentrating on cars with high profit margins in order to avoid a large impact on their financial figures. But we could see that customer satisfaction was especially negatively impacted with long waiting times for deliveries. I think generally this was a wake up call for the industry seeing that they have to change their production processes. Too many OEMs are not combining hardware and software at all but rather see it as two different components - this is something that is definitely changing and OEMs need to adapt to it.

Do you believe this strategy to be beneficial for a different crisis or just the chip shortage? Why?	Yes, the strategy focuses on what manufacturers can directly influence and are able to control without relying on third parties for chip production. For a short term solution it was the ideal resource allocation, because resources are scarce and then they determined how to allocate those resources to maximize profit, and try to buffer customer satisfaction. However, a more proactive approach would have been to broaden supplier base to alleviate dependency, use universal chips, not be so dependent on specific chips or be manufactured in high volumes
Do you believe this strategy to be beneficial for a different crisis or just the chip shortage? Why?	The strategy change is a very reactive solution and behavior. The most proactive approach to dealing with this issue would be to diversify the supply base to reduce the dependency on for example just one supplier. It would be beneficial to focus on using universal chips, rather than specific chips to further reduce the dependency. Also it should be considered to produce components in higher volumes to have a buffer against any potential supply-chain disruptions. On a short term reactive basis the strategy was beneficial, but long term other changes have to be made.
Do you believe this provides a competitive advantage compared to what other companies are currently doing? If yes, to what extent?	It did allow the OEM to remain financially strong and this is definitely a competitive advantage they will have over other OEMs who were not able to come out- until now - so strongly. To focus long term only on the luxury segment can be difficult, as the largest brand segment are low cost cars. The high-cost luxury segment is very demanding in terms of quality production, and in order to remain competitive in the

	long term, volume manufacturers also need to focus on low cost cars

Appendix B: Teaching Notes Addition

Table 7: Lesson 1 Detailed Structure and Description

Step	Activity	Time
(1) Introduction to Beer Game	Present Slide Deck to explain rules & necessary information of Beer Game and provide link to the actual Beer Game (http://scgames.bauer.uh.edu/, teachers must ensure beforehand that their institution is listed and can participate)	10 Minutes
(2) Building Groups	Divide Class into two sets (depending on the group size): Each Set will have 4 groups: Retailer, Wholesaler, Distributor and Factory. The teacher must ensure that once the game starts the groups are no longer communicating with each other only within the group.	5 Minutes
(3) Start first half	The Groups will be asked to login to the game as their respective group and start the game. It is recommend to display the live changes of the supply chain on the beamer (if this provided by the game)	15 Minutes
(4) Compare & Discuss first findings	After their last order round has been placed the teacher will present to the students data and how their game went (data will be provided through teacher login in the game). The two sets of groups will be compared to each other to see which supply chain has been performing	15 Minutes

	better. Students are then asked to discuss and analyze the data and get possible first learnings	
(5) Start second half	After analyzing the data the groups will reconvene and start the game again. The goal is for the students to have taken learnings from the discussion and manage to avoid the BE by ordering more rationally.	15 Minutes
(6) Compare & Discuss second findings	Before presenting the data the teacher should ask the students how they believe they performed in the second round. Afterwards the data will be presented and the performance of both groups compared and analyzed	15 Minutes
(7) End Remarks	It is recommend that the professor provides some end remarks and summarizing the findings and BE for the students	15 Minutes

Table 8: Lesson 2 Discussion Questions

The following questions are an aid for the instructure to spark discussions with the students and create the same knowledge basis for all. The recommend questions set here refers to 5Cs[15]

Topic	Questions
Company	• What does the company do and what is its mission and vision? • What are the revenue sources of the company? • What motivates the Management Level?
Context	• How did the company end up in its situation? • What industry is the company in? • What is known about the current situation of the company (

[15] retrieved from: https://corporatefinanceinstitute.com/resources/management/5c-analysis-marketing/

	threats, opportunities, strengths, weaknesses etc)
Competition	• Who are competitors? • What is the company's competitive advantage? • How strong is the competition?
Clients	• How is the customer base segmented? • Who are the most important customers for the company?
Collaborators	• Who are major stakeholders and what is their motivation to be in business with the company? • What are current and future potential partners?

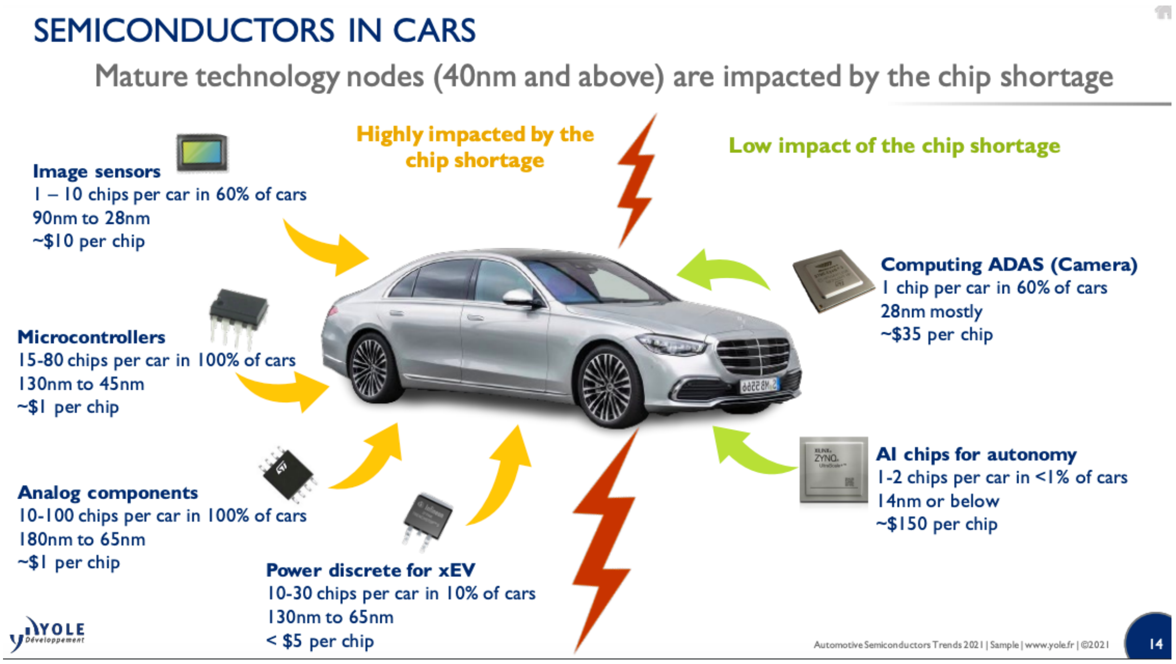
retrieved from:

The instructor can use these questions to help students distinguish between important matters and peripheral topics, as well as between the underlying issues and the observable effects of the problem:

- What is the actual problem?
- Is the issue critical?
- Why should this problem be addressed?
- Who should be addressing this problem?

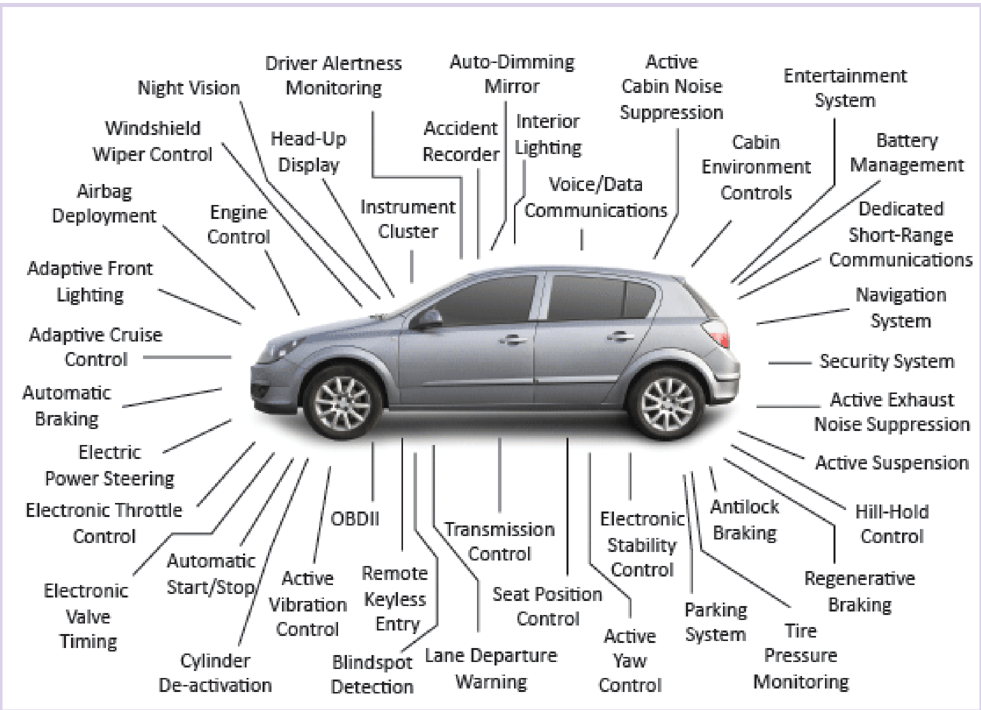
Appendix C: Exhibits

Exhibit 1: Usage of semiconductors in cars



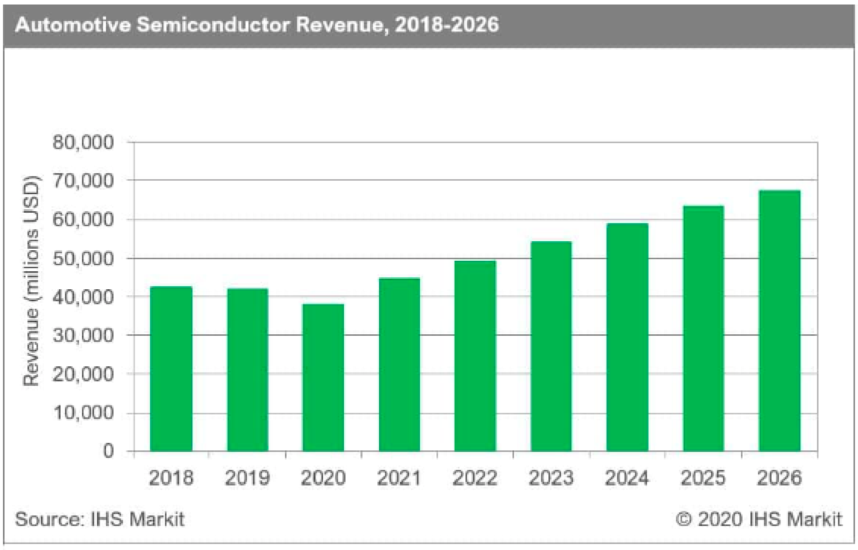
retrieved from: Hackmann et al., 2022,
https://www.p3-group.com/wp-content/uploads/2022/06/220603-P3-Halbleiter-Pra%CC%88sentation-v01.pdf

Exhibit 2: Sample of the electronic systems within cars



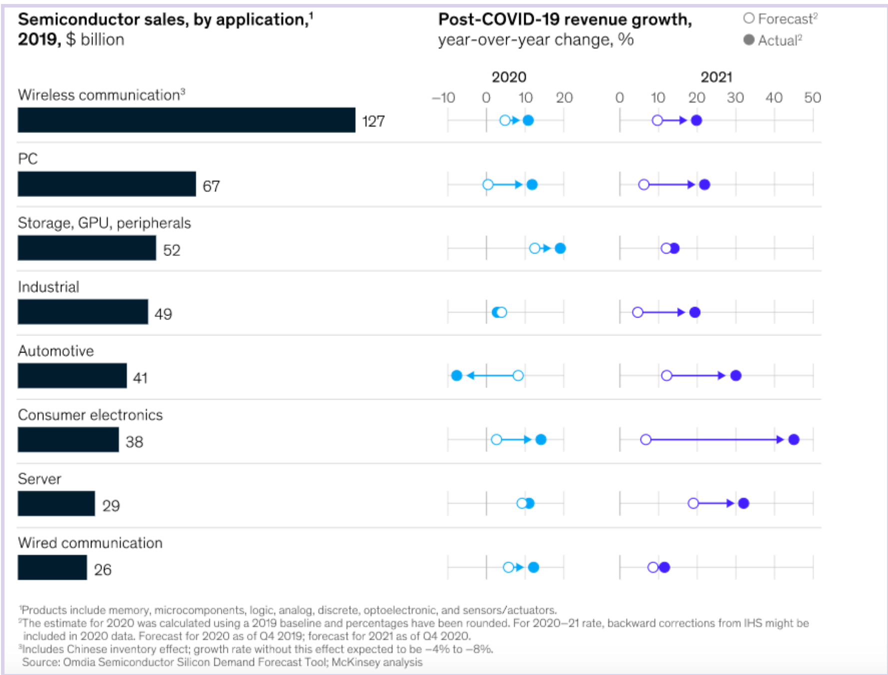
retrieved from: (Murphy & Hogan, 2015),
https://semiengineering.com/quality-and-safety-in-automotive-electronics-venturing-beyond-iso-26262/

Exhibit 3: Automotive Semiconductor Revenue, 2018 - 2026



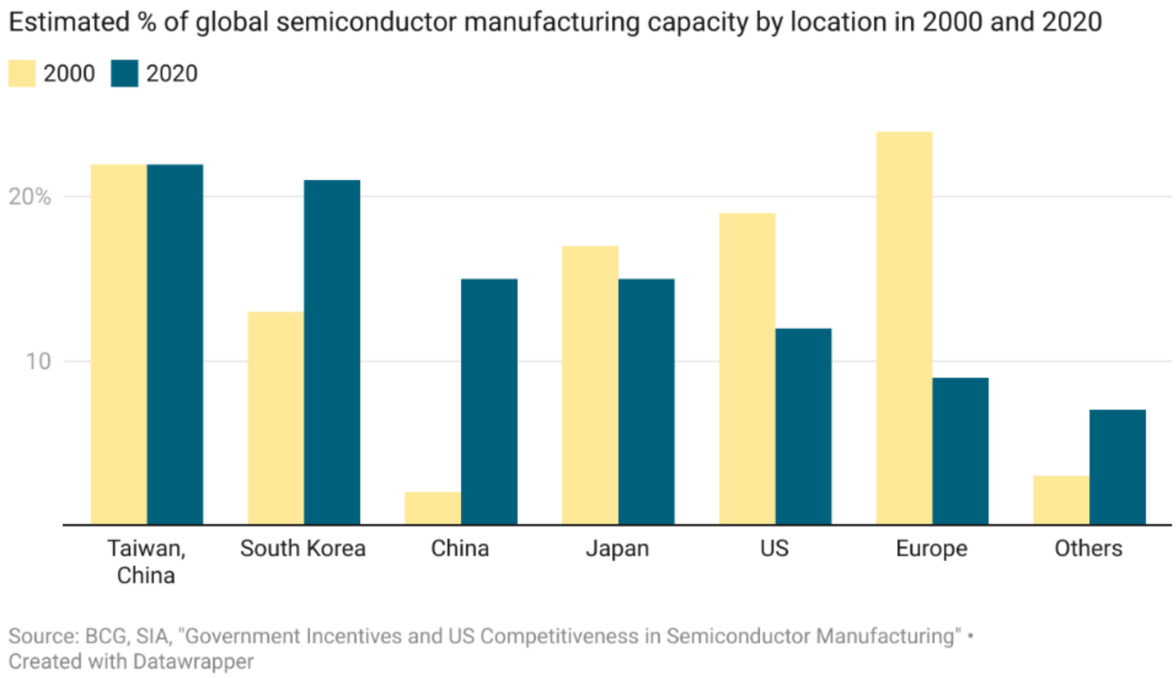
retrieved from: (Amsrud, 2020),
https://www.spglobal.com/mobility/en/research-analysis/global-automotive-semiconductor-revenue-in-2020.html

Exhibit 4: Semiconductor sales by application and post Covid revenue growth



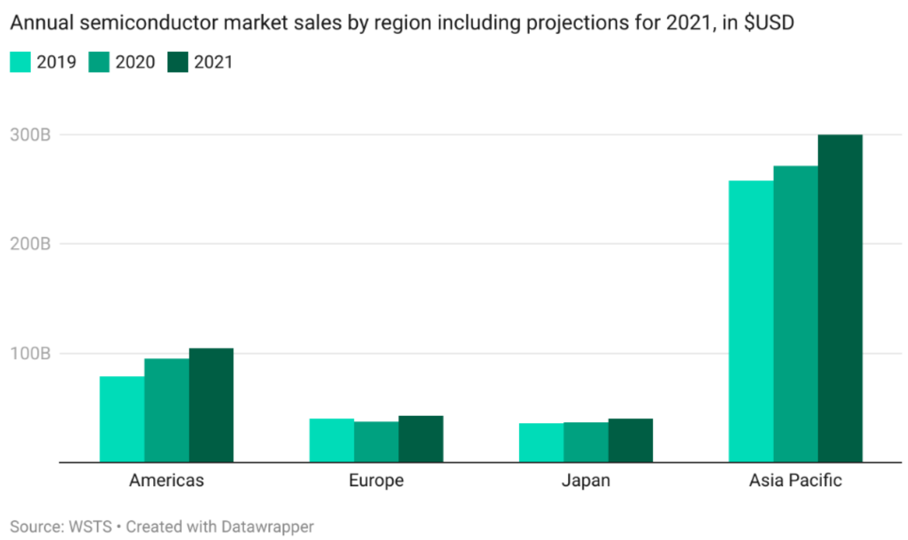
retrieved from: (Burkacky et al., 2022)
https://www.mckinsey.com/industries/semiconductors/our-insights/semiconductor-shortage-how-the-automotive-industry-can-succeed

Exhibit 5: Semiconductor manufacturing capacity by location (2000 and 2020)



retrieved from: (Letzing, 2021) *https://www.weforum.org/agenda/2021/05/what-s-the-bullwhip-effect-and-how-can-we-avoid-crises-like-the-global-chip-shortage/*

Exhibit 6: Annual semiconductor market sales by region



retrieved from: (Letzing, 2021) *https://www.weforum.org/agenda/2021/05/what-s-the-bullwhip-effect-and-how-can-we-avoid-crises-like-the-global-chip-shortage/*

Exhibit 7: Semiconductor development and production timelines

Semiconductor development and production timelines

	Capacity buildup		Product development		Production
	New fab buildup	Fab ramp	Chip design[1]	Yield and volume ramp-up	Production (cycle time)
Approximate typical duration, months	12–18	6–18	12–36[2]	6 or more	4 or more
Influencing factors	•Clean-room building •Facilitation (HVAC, gas, electric, etc)	•Tool lead times •Hookup and qualification	•Product complexity	•Product complexity •Fab utilization	•Product complexity •Physical and chemical processes •Fab utilization
Other considerations		Required for expansion of existing plant		Required when transferring existing product between fabs	

Fab-ramp and chip-design stages may run in parallel

[1]Chip design can be driven independent of fab manufacturing capacity.
[2]Eg, ~12-month product lifecycle for mobile phones; 24–36-month development time for automotive microcontroller units.
Source: McKinsey analysis

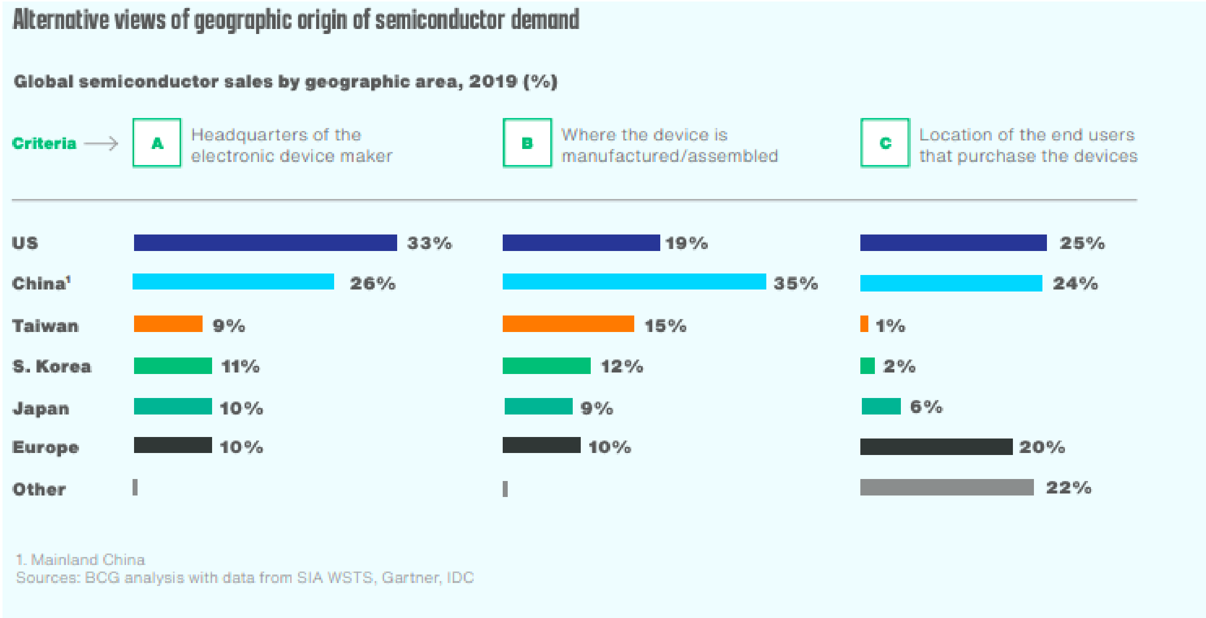
retrieved from: (Burkacky et al., 2021)

https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/coping-with-the-auto-semiconductor-shortage-strategies-for-success

Exhibit 8: Semiconductor factories expansion in Germany

retrieved from: Hackmann et al., 2022,
https://www.p3-group.com/wp-content/uploads/2022/06/220603-P3-Halbleiter-Pra%CC%88sentation-v01.pdf

Exhibit 9: Geographic origin of semiconductor demand and production

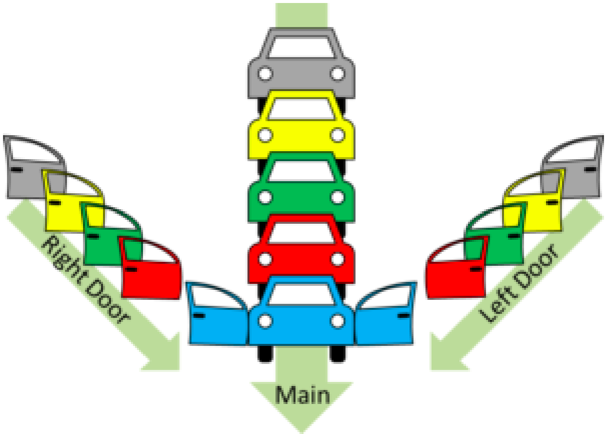


retrieved from: (Varas et al., 2021)
https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

Exhibit 10: Automotive semiconductor supply chain steps with examples

retrieved from: (Wang, 2021)
https://www.counterpointresearch.com/semiconductor-component-shortage-hits-automobile-industry/

Exhibit 11: Just-in-Sequence Assembly



retrieved from: (Roser, 2017)

https://www.allaboutlean.com/just-in-sequence-definition/

Basic Idea:

- Having the parts delivered to the assembly line in the order they need to be put into the car
- Allows for very low inventory and storage costs

Exhibit 12: Just-in-Time Assembly

retrieved from: (Banton, 2022)

https://www.investopedia.com/terms/j/jit.asp

Basic Idea:

- deliver the necessary parts in bulk just when it was needed for production, i.e. on the exact day (just-in-time)
- short production runs and reduced inventory level

8. References

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