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Supply Disruption Response in Semiconductor Crisis

Master's thesis in Supply Chain Management

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Abstract

The automotive industry faced significant challenges during the semiconductor crisis from early 2020 to late-2023. The crisis, initially triggered by the Covid-19 outbreak, led to a mismatch between supply and demand by the fourth quarter of 2020, persisting until the crisis's end. Multiple disruptive events further worsened the semiconductor shortage. Due to the high demand for consumer electronics, the challenge of acquiring semiconductors for OEMs became even greater, forcing them to quickly implement measures to mitigate these disruptions effectively.

This case study investigates the measures adopted during the different phases of supply chain disruption, and identifies lessons learned for managing future disruptions. This case study also questions which measures were integrated into the current process and why some were integrated while others were not. A qualitative study approach was used that consisted of interviewing internal stakeholders, complemented by a quantitative analysis of previously assembled internal documents. The findings are represented by the correlation of supply chain resilience in the automotive industry related to its flexibility, robustness, visibility, and measure interconnectedness over time.

This case study reveals that measures that are taken initially during a crisis are typically flexible measures and, after their integration into standard operations, they become more robust processes. The report underscores the importance of strategic measure implementation during disruptive events like the semiconductor crisis. By adopting flexible measures initially and transitioning to robust processes, companies can increase their chances of managing disruptions and maintain operational continuity. The case study emphasizes that a well-planned progression from flexibility to robustness can help build long-term supply chain resilience, ensuring that organizations are prepared for future crises and maintaining their operational continuity.

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Keywords: *Semiconductor*, *Disruptions, Measures, Supply Chain Resilience, Flexibility, Robustness, Visibility*.

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Albin Sabani and Parsa Pichkah, Gothenburg, May 2024

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1. Introduction

The introduction serves as a foundational framework for the study, offering insights into the background context that motivates the research. It delves into the broader landscape surrounding the study's subject matter, providing context for the significance of the research questions that will be explored. Additionally, the introduction articulates the purpose of the study, explaining the aims and objectives that will guide the research process.

1.1 Background

The automotive industry, a critical component of the global economy, currently faces uncommon challenges rooted in its complex network of suppliers. Recent years have notably highlighted the industry's vulnerabilities to such challenges, especially evident during the semiconductor shortage crisis which not only disrupted production but also caused significant financial losses (Garcia et al., 2023). Furthermore, as the industry undergoes a shift towards electrification, the frequency of electrical component shortages escalated during the crisis across the majority of supply chain industries (Gray-Fow, E. 2019). Due to the high demand for consumer electronics, the challenge of acquiring semiconductors for OEMs became even greater, making the situation worse for the automotive industry (Chin, 2021). Such dynamics emphasize the critical need for automotive Original Equipment Manufacturers (OEMs) and their suppliers to develop resilient strategies essential for mitigating these impacts, ensuring continuity in operations, and maintaining competitive positions in the industry (Frieske & Stieler, 2022).

This vulnerability is further worsened by several disruptions within the semiconductor industry, which significantly affect the automotive sector, characterized by prolonged production times of 12 to 16 weeks and a heavy dependence on East Asian manufacturing. External factors such as natural disasters amplify these risks (AX3, Senior Purchaser, personal communication, 2024). The COVID-19 outbreak, in particular, has increased lead times even more and stimulated demand for advanced chips further, notably impacting consumer electronics and computing sectors (A7, Procurement Advisor, personal communication, 2024). As the semiconductor industry continues its shift towards newer technologies, automotive OEMs face strategic challenges due to their reliance on older generation chips, highlighting a gap in resilience and strategic alignment. Managing these disruptions effectively requires a structured response, involving factors such as, diagnosis, development, and implementation of strategic measures (Bode & MacDonald, 2016). This structured approach emphasizes understanding the power dynamics and the administration in buyer and supplier relationships to control supplier behaviour and minimize the impact of disruptions (Lee et al., 2023).

Expanding on the concept of structured response, Sheffi and Rice (2005) emphasize the importance of segregating measures across different segments to effectively counter the varied consequences of disruptions over time. They advocate for the integration of flexibility, redundancy, and robustness within supply chains to enhance resilience. Flexibility enables firms to adapt to market fluctuations and gain competitive advantages promptly, while redundancy involves maintaining reserve resources to manage emergencies, and robustness ensures that uniform processes across locations can facilitate agile responses to disruptions over time. Extending this framework, Ponis and Ntalla (2016) categorize decision making in supply chain crisis management into three stages: preparedness, response during the disruption, and post-crisis recovery. This model highlights the need for strong relationships, capacity flexibility, multiple sourcing, effective communication, and proactive crisis management systems. Further elaborating on the response to disruption, Küffner et al. (2022) detail the series of

interconnected waves, initial, temporary and post-disruption, where actions in one phase influence and inform strategies in the next phases, demonstrating the interconnectedness of measures in a comprehensive approach to managing disruptions.
Building on the insights from Sheffi, Rice, Ponis, Ntalla, and Küffner et al., which highlight the necessity of segmented and strategic responses to supply chain disruptions, this research report seeks to address a critical gap by applying these theories to the real world context of automotive OEMs. Specifically, the study will investigate the initial reactive measures, the during disruption measures and the post-crisis measures implemented by OEMs during the semiconductor crisis. These inquiries are essential for dissecting how OEMs' management of semiconductor shortages evolves through a crisis, and align closely with the research questions formulated to explore the practical applications of theoretical supply chain management principles.

1.2 Purpose

The main purpose of this thesis is to contribute to the understanding of how supply chains in the automotive industry react to semiconductor shortages. The study aims to investigate the measures adopted during different phases of supply disruption. Furthermore, it tries to find out how these measures were developed after disruption. In so doing, the thesis intends to provide practical insight that can help OEMs better manage future disruptions and build their supply resilience.

1.3 Research Questions

It is critical to understand what measures OEMs have taken in response to semiconductor shortages initially and during the crisis. Knowing such measures helps in understanding their effectiveness and provides insights into the management of future disruptions. The first research question identifies such strategies as key to learning how impact can be minimized and operational continuity maintained during similar disruptions.
As shortages persist, it is essential to study which measures initially adopted and those implemented during the crisis have been integrated into current processes. The second research question focuses, therefore, on identifying these measures to understand why they have been retained in the operations post-crisis. Evaluating these measures helps in recognizing which successful strategies enhanced the company's resilience and adaptability for future disruptions.
Post-crisis periods provide insights into long-term strategic shifts within a company. The third research question examines why certain measures were continued or omitted after the crisis. Understanding these long-term impacts helps in shaping robust supply chain strategies to withstand future disruptions.

1. What measures were adopted by Company A in response to semiconductor shortages?

2. Which measures are omitted or included in today’s processes?

3. Why did certain measures get included or omitted?

1.5 Outline of the report

Figure 1, Outline of the Report

2. Literature Review

During the case study of Company A's procurement department, a comprehensive review of existing literature on the subject of procurement, supply chain and purchasing was carried out. The objective of this literature review was to acquire a thorough comprehension of the landscape of the automotive industry and the shortage of materials during supply chain disruption. The review taught insights into the methodologies employed, the interviews executed, and the potential enhancement into Company A's procurement procedures within the purchasing department.

2.1 Semiconductor Supply Chain

The semiconductor supply chain, valued at half a trillion dollars, is one of the world's most advanced industries, with the production of a single electronic chip often requiring over 1,000 steps and crossing international borders more than 70 times before reaching the end customer (Khan, et al., 2021). This complexity is further complicated by the geographical dispersion of which include several specialized manufacturing processes (Baldwin & Freeman, 2022). Policies or disruptions impacting even a single actor or a specific step in the supply chain can have widespread effects, resulting in substantial negative consequences (Varas et al., 2021). Therefore, it is crucial for actors within the industry to gain a comprehensive understanding of the semiconductor supply chain and the competitive dynamics within each sector to avoid unintended negative impacts (Semiconductor Industry Association, 2021).

2.1.1 Overall Semiconductor Supply Chain

The semiconductor supply chain includes several interlinked phases that drive the global industry (Wai-Chung Yeung et al., 2022). It starts with research and development (R&D) which stands as a foundational base that supports the semiconductor design process, a critical and knowledge intensive stage that includes different firms from integrated device manufacturers to fabless companies (Wai-Chung Yeung et al., 2022). These entities invest heavily in developing advanced chips that form the backbone of hightech applications (Wai-Chung Yeung et al., 2022).

Wai-Chung Yeung et al., (2022) further explains that the manufacturing of semiconductors is divided into front-end and back-end processes. The front-end involves wafer fabrication and the back-end process, which is less capital intensive, includes assembly, packaging, and testing of the silicon wafers into final chips ready for market.

Supporting these manufacturing processes are specialized segments that provide materials that are needed for production and various tools supporting technology (Wai-Chung Yeung et al., 2022). The tools supporting technology are known as Electronic Design Automation (EDA) software, which aids in chip design, and semiconductor manufacturing equipment, which is crucial for both front-end and back-end processes (Wai-Chung Yeung et al., 2022). The value chain is influenced by a global network of suppliers and manufacturers, making it sensitive to different disruptions, requiring continuous innovation and strategic management to maintain efficiency and competitiveness (Wai-Chung Yeung et al., 2022).

Figure 2, Semiconductor Manufacturing Process, (Wai-Chung Yeung et al., 2022).

Semiconductor R&D

R&D involves fundamental research to advance chip design and manufacturing technologies, with significant positive externalities (Wai-Chung Yeung et al., 2022). China for instance has started establishing semiconductor design through various AI technologies (Khan, et al., 2021). Semiconductor R&D differs from other industrial R&D processes since it is such a crucial component and often receives government support (Wai-Chung Yeung et al., 2022). Government backing, as seen in programs like the National Extreme Ultraviolet Lithography Program in the US, has been instrumental in advancing semiconductor R&D projects.

Semiconductor Design

Khan, et al. (2021) discuss the global landscape of semiconductor design, with the United States, South Korea, and Europe being major players. China is emerging as a competitor, particularly in a specific type of electronics chip. The U.S. dominates in CPU and GPU design, while China focuses on developing its own chips. Memory chip production is primarily controlled by South Korea, the United States, and Japan. These chips are crucial components in various industries, including automotive manufacturing (Khan, et al., 2021).

The design of semiconductors is a complex and costly process, requiring significant investments in research and development (Wai-Chung Yeung et al., 2022). It involves various types of firms, including IDM firms, fabeless design houses, and new players like system platform companies (Wai-Chung Yeung et al., 2022). Designing cutting-edge processors or systems-on-chips, demands substantial resources and expertise (Wai-Chung Yeung et al., 2022). The US dominates the global chip design market (Khan, et al., 2021).

Semiconductor Manufacturing

The semiconductor manufacturing process is divided into two critical stages: the front-end and back-end (Techlevated, 2024), which are explained further down. In the front-end, essential components such as transistors and capacitors are created on a silicon wafer using various techniques (Techlevated, 2024). Following this, the back-end process encompasses interconnecting, packaging, and testing these components to ensure they function correctly (Techlevated, 2024).

Despite these stages being distinct, they are deeply interconnected. The design and execution in the front-end stage must take into account the specifications required for the subsequent back-end processes (Techlevated, 2024).

To optimize the entire manufacturing workflow, there is a crucial, ongoing exchange of feedback between the relevant parties involved in both stages. The insights gained from back-end testing can lead to refinements in the front-end processes to enhance the overall quality and yield of the semiconductor chips (Techlevated, 2024).

- **Front-end**

Major semiconductor fabs are concentrated in the US, Taiwan, South Korea, Japan, and China, controlling the majority of the global market (Khan, et al., 2021). Wafer fabrication, a crucial step in semiconductor manufacturing, involves hundreds of intricate processes and takes several weeks to complete (Wai-Chung Yeung et al., 2022). It requires various inputs and specialized equipment, with each wafer containing numerous advanced chip cores packed with billions of transistors (Wai-Chung Yeung et al., 2022). Fabrication, particularly with complex wafers, is capital intensive, requiring investments of tens of billions of dollars (Wai-Chung Yeung et al., 2022). Operating advanced fabs demands extensive knowledge and expertise across multiple disciplines (Wai-Chung Yeung et al., 2022).

- **Back-end**

ATP, or assembly and test packing, essential in the semiconductor supply chain, encompasses the back end of manufacturing, conducted in-house or outsourced (Khan, et al., 2021). Back end manufacturing entails transforming silicon wafers produced by front-end fabs into finished chips ready to be fitted into electronic modules and final devices (Wai-Chung Yeung et al., 2022). Main providers are based in Taiwan, the US, China, and South Korea (Khan, et al., 2021). China has developed a strong ATP industry, non-chinese firms have however established significant presence in China (Khan, et al., 2021). Despite historically being low value, packaging has become crucial for chip performance, especially as transistors densities increase, leading to communication bottlenecks (Khan, et al., 2021).

2.1.2 Automotive Multi-tier Semiconductor Supply Chain

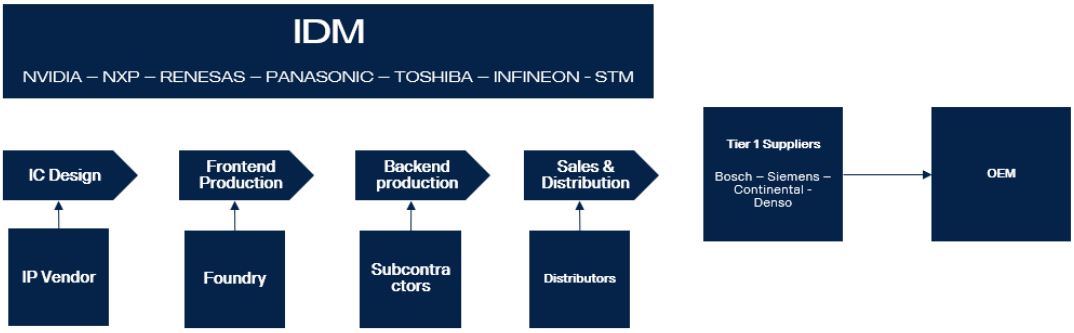

Figure 3, Semiconductor Supply Chain, (AX3, Senior Purchaser, personal communication, 2024; Chen, 2019)

The semiconductor supply chain, as illustrated in figure 3, is a multi-tier system involving multiple actors that together produce a final product. This chain is primarily comprised of Tier 2 suppliers, recognized as semiconductor manufacturers, and Tier 1 suppliers who directly provide finalized components to Original Equipment Manufacturers (OEMs). At its core, the semiconductor value chain includes Integrated Device Manufacturers (IDMs), who may choose to outsource parts of production to entities such as IP vendors, foundries responsible for front-end manufacturing, or subcontractors handling back-end manufacturing. While some IDMs keep all production in-house, others opt to outsource the entire process (Chen, 2019).

After production, components are sent to Tier 1 suppliers, who integrate the chips into electronic systems. OEMs then procure these systems from Tier 1 suppliers for incorporation into final products. To enhance supply chain visibility and resilience, especially during disruptive events, Tier 1 suppliers may establish direct communication with Tier 2 suppliers, adding layers of complexity to supply chain dynamics (Chen, 2019).

Sauer and Seuring (2018) highlight the complexities of modern supply chains, which integrate diverse contexts, actors, and industries to deliver competitive products. They note that a firm's awareness of its supply chain participants diminishes as physical and cultural distances increase, and as more tiers exist between the firm and its suppliers. This issue is particularly critical for companies focused on sustainability, as the practices of raw material suppliers at the beginning of the supply chain significantly influence sustainability outcomes.

In the complex landscape of the OEM industry, rapid response capabilities are critical for navigating challenges in an uncertain demand environment. Nakashima and Sornmanapong (2013) emphasize the necessity for deeply integrated and collaborative relationships across multi-tier supply chains to enhance these capabilities. Central to their argument is that without robust mutual cooperation and a vigorous exchange of information, efforts to reduce lead times are likely to fall short. This comprehensive sharing of information and knowledge between OEM manufacturers and their first-tier

suppliers ensures all parties develop a clear understanding of the operational requirements, costs, and benefits involved, aligning and informing all stakeholders.
However, this level of interaction has not consistently extended beyond the first tier. While OEMs have cultivated highly collaborative and structured relationships with their first-tier suppliers, the gap in information sharing between the first and second tiers often leaves second-tier suppliers unable to adapt to sudden changes in demand. This disconnect at the second tier of suppliers manifests as a critical bottleneck within the supply chain, undermining the agility and efficiency that the system strives to achieve. Addressing this issue requires an expansion of the collaborative and information-sharing practices that have proven effective between OEMs and their first-tier suppliers, fostering similar relationships that include second-tier suppliers to enhance the overall responsiveness and efficiency of the entire supply chain (Nakashima & Sornmanapong, 2013).

2.1.3 Semiconductor Supply Chain Disruptions

One major challenge the semiconductor industry faces is the increase in average lead time, especially during disruptive events like the COVID-19 outbreak. The lead time, in regard to semiconductors, refers to the duration from ordering to receiving semiconductor products, and disruptions can significantly impact this process. The pandemic emphasized the situation by increasing the demand for advanced chips, particularly in consumer electronics and computing sectors (Ochonogor et al., 2023). The industry operates on various different business models, each with its advantages and challenges and it influences how companies design and manufacture components (Ochonogor et al., 2023).
Several factors contribute to disruptions in the semiconductor industry, including increased consumer demand, reliance on East Asian countries for manufacturing, and logistical issues such as sanctions, geopolitical tensions, and global trade policies. Natural disasters can also be a cause. Another critical aspect is capacity utilization, as the industry moves toward newer technologies, sectors dependent on older generation chips, like the automotive, face increased risks in storing components and trying to secure the future (Ochonogor et al., 2023).
Overall, the semiconductor industry faces several complex challenges including supply chain disruptions, technological transitions and global market dynamics, requiring constant adaptation and resilient strategies to navigate the supply chain effectively (Varas et al., 2021).

2.2 Supply Chain Resilience

Supply Chain Resilience, a blend of reactive and proactive approaches, balances adaptability and stability (Durach et al., 2015). Procurement plays a pivotal role in the pursuit of achieving supply chain resilience, as highlighted in the research conducted by Pereira et al. (2014). The study emphasizes how flexibility, robustness, and visibility are specifically linked to procurement activities, contributing significantly to the resilience of the supply chain.
Flexibility is a key enabler of resilience within procurement strategies. Roberta Pereira et al. (2014) emphasize the importance of sourcing flexibility, product flexibility, process flexibility, etc.. They argue that these forms of flexibility empower organizations to easier adapt to disruptions and environmental changes, such as shifting supply sources, altering product designs, or changing transportation modes. By embracing flexibility, companies enhance their ability to respond effectively to unexpected events, thus benefiting the resilience of the supply chain.
Robustness is intertwined with procurement practices highlighted in the study. Roberta Pereira et al. (2014) suggest that redundancy in critical components and safety stock management for instance are measures that contribute to robustness within the supply

chain. These measures provide backup options and mitigate the impact of disruptions, thereby strengthening the resilience of procurement operations and the broader supply chain.

Visibility emerges as another critical aspect emphasized in the study concerning procurement's role in enhancing supply chain resilience. Roberta Pereira et al. (2014) emphasize the significance of information sharing, technological tools, and workers' knowledge in maintaining visibility across the supply chain. Improved visibility enables procurement/supply chain activities to accurately forecast demand, manage inventories, and coordinate with suppliers, thereby enhancing the overall resilience of the supply chain.

In summary, Roberta Pereira et al.'s (2014) research elucidates how flexibility, robustness, and visibility are interconnected with procurement/supply chain activities, emphasizing their importance in creating supply chain resilience. By embracing flexible strategies, ensuring robust management practices, and enhancing visibility across the supply chain, procurement functions contribute significantly to securing the resilience of organizations in the face of disruptions and uncertainties.

2.2.1 Categorizing Measure Implementation Across Disruption Phases

In their article, Sheffi and Rice (2005) emphasize the significance of segregating measures adopted by companies across different segments to effectively mitigate the varied consequences of disruptions over time and promote resilience. The authors highlight that relying on flexibility, redundancy, and standardization is crucial when it comes to segregation in order to safeguard against vulnerabilities arising from supply chain disruptions. Including flexibility into supply chains enables companies to adeptly respond to market fluctuations, reduce expenses, and gain competitive advantage (Sheffi & Rice, 2005). Additionally, the article delves into the concept of redundancy as a means of managing disruptions, which entails maintaining reserve resources for emergency use. This approach underscores the significance of standardization, where uniformity in processes, equipment, and practices across various locations facilitate agile responses to disruptions through interchangeable operations (Sheffi & Rice, 2005).

Building on this perspective, to effectively manage and understand the actions and strategies crucial to managing a supply chain disruption, decision making in the supply chain crisis management is organized into three categories that influence a company’s ability to recover (Ponis & Ntalla, 2016) (Sheffi & Rice, 2005). For the initial stage, the focus is on preparedness, companies are advised to build strong relationships and ensure capacity flexibility, as well as strategies for multiple sourcing. Effective communication collaboration management and the risks of sole reliance on one supplier are highlighted during the second stage, during the disruption. After a crisis, recovery efforts led by leadership and proactive crisis management systems are focal points to support long term resilience.

Furthermore, after dividing the response to disruption into three waves, initial, temporary and post-disruption, Kuffner et al. (2022) emphasize the necessity of recognizing the interconnectedness of these responses over time. Actions taken during one phase influence decisions and strategies in the subsequent phases, with each set of measures building on the outcome of the previous one (Küffner et al., 2022). The interrelationship aspect comes into play as the measures in one phase inform and shape the actions in the next (Küffner et al., 2022). Overall, each set of measures is not isolated, they are rather interconnected steps in a comprehensive approach to managing supply chain disruptions (Küffner et al., 2022).

Moreover, measures aimed at mitigating or managing supply chain disruption can be further categorized and are very well supported by categorizations in literature. Measures taken by a company can be divided into internal and external measures in order to simplify the process of understanding them. By integrating internal and

external measures, companies can build a more resilient supply chain that withstands disruptions and thrives during uncertain periods. This approach ensures operational efficiency and provides a competitive edge, making companies better prepared for challenges that may occur throughout the supply chain (Deloitte, 2022).

Internal Measures

Internally, companies are advised to implement different types of measures that can help the company mitigate risks and enhance resilience in their supply chain. Digital tools and advanced technologies help to enhance visibility and real-time monitoring across their supply chains. These technologies improve decision-making capabilities and help predict or mitigate potential disruptions (Kilpatrick et al., 2024). Additionally, robust scenario planning and risk management frameworks are crucial. These frameworks should be updated in real time to remain as effective as possible, allowing companies to anticipate various disruptive events through creating plans (Kilpatrick et al., 2024).

Inventory management is also a critical internal measure. Maintaining optimal inventory levels, including safety stock, acts as a buffer against disruptive events. Adopting inventory strategies alongside just-in-time approaches helps companies respond quickly to unexpected disruptions (Kilpatrick et al., 2024). Further, developing flexible product designs allows quick adaptation to changing circumstances Carla Roberta et al.

Tarigan, et.al. (2021) explains in their article that companies should focus on integrating their processes with each other to create better coordination and communication within the departments. This involves the implementation of several internal measures, be it of technological nature or standard procedures. By aligning the information systems, also, the company fosters collaborative planning and thereby responds to disruptions quickly.

External Measures

Externally, geographical and supplier diversification are key strategies. Restructuring supply bases to include options reduces reliance on distant suppliers and mitigates risks related to geological disruptive events. Engaging multiple suppliers for critical components and ensuring they are geographically dispersed minimizes the impact of localized disruptions and enhances supply chain flexibility (Kilpatrick et al., 2024).

Effective supplier relationship management, through regular communication and collaboration, performance monitoring, and development programs, is essential to ensure suppliers meet required standards and reduce dependency on any single supplier (Kilpatrick et al., 2024). Moreover, Roberta Pereira, et.al., (2014) explains the importance of strategic sourcing and the development of criteria for supplier selection that consider financial stability, capacity, and flexibility. This includes managing a balanced supplier base to avoid reliance on a single supplier. Collaborative partnerships with suppliers and other actors within the supply chain significantly enhances resilience. Applying this helps companies share best practices and resources, strengthening their collective ability to respond to disruptions (Kilpatrick et al., 2024).

Tarigan, et.al. (2021) emphasizes the external measure by explaining the importance of building strong relationships with suppliers. Long-term collaboration with suppliers enhances the information sharing and results in smoother operations between the different actors in the supply chain. These external measures help the company in adapting to changes in demand during uncertain periods.

2.2.2 Flexible and Robust Supply Chains

To effectively manage supply chain disruptions, it is crucial for companies to understand the types of disruptions and their impact on the organization (Ambulkar et al., 2015). According to the authors, a company must strike a balance between two orientations: resource reconfiguration and risk management infrastructure. A resource

reconfiguration approach allows companies to adapt, by realigning their resources to mitigate threats and seize opportunities. Firms proficient in reconfiguring their resource base are better equipped to develop capabilities that enhance resilience to disruptions. This orientation motivates firms to proactively manage resources to respond effectively to disruptions. The mediating role of resource reconfiguration between supply chain disruption orientation and firm resilience depends on the level of disruption impact faced by the firm. In high-impact disruption situations, resource reconfiguration acts as an intermediary mechanism enabling firms to develop resilience. However, in low-impact disruption scenarios, over-reliance on this approach might neglect other resilience-building strategies, potentially leading to high costs, organizational instability, and disruption of operations (Ambulkar et al., 2015).

Regarding the risk management infrastructure orientation, it involves the resources and structures a firm employs to manage supply chain risks and disruptions, including dedicated departments, information systems, and performance metrics (Ambulkar et al., 2015). A robust risk management infrastructure enables firms to respond efficiently to disruptions by reducing ambiguity, facilitating task specialization, and leveraging prior experiences. However, in the face of high-impact disruptions, reliance on established risk mitigation approaches may hinder firms from adopting creative and flexible responses, potentially limiting resilience (Ambulkar et al., 2015).

Flexibility

Flexibility within a Supply Chain is crucial for swift responses to disruptions while minimizing drawbacks, often achieved through redundancy, which entails maintaining surplus resources like inventory and capacity (Carbonara & Pellegrino, 2017). Practices aimed at reducing disruption risks through flexibility and redundancy include postponement, strategic stock, multiple sourcing, the make-and-buy strategy, and flexible supply contracts (Carbonara & Pellegrino, 2017). While flexibility provides immediate response capacity, it can also lead to increased inventory levels, posing potential risks to a company's operations (Sheffi & Rice, 2005).

However, Christopher Tang and Brian Tomlin present a comprehensive framework emphasizing why limited flexibility can effectively manage supply chain risks, particularly within the context of multiple sourcing, surplus capacity, postponement, and flexible pricing (Tang & Tomlin, 2009). They suggest that significant benefits can be attained without requiring extensive investments in flexibility (Tang & Tomlin, 2009).

Similarly, Kuffner et al. highlight the importance of Purchasing and Supply Management (PSM) in enhancing flexibility within the supply chain. Their approach includes internal employee training, establishing recovery processes, seeking additional sourcing bases, and expanding collaborations (Küffner et al., 2022). This multifaceted perspective underscores the nuanced strategies available for optimizing supply chain flexibility (Küffner et al., 2022).

Robust Supply Chains

Robustness hinges on preserving flexibility across the different phases of disruption response measures (Klibi et al., 2010). These measures can be categorized into three different phases: initial, temporary, and post-disruption (Kuffner et al.). Flexibility offers a versatile framework with numerous options for addressing disruptions, capable of evolving into robust processes for future disruptive events (Klibi et al., 2010). The challenge at hand is to strike a balance between achieving the required level of robustness in the system while simultaneously managing complexity. This involves ensuring that the system is resilient enough to withstand disruption and uncertainties, while also maintaining a degree of flexibility, as it can lead to costs and inefficiencies (Monostori, 2018). Another challenge lies in the misconception of robustness, as it may be mistakenly perceived as a static concept, when in fact, it often necessitates structural or component level changes to uphold functionality (Brandon-Jones et al., 2014).

Brandon-Jones et al., (2014) explain in their article that robustness is the ability of supply chains to handle disruptions without major functional failures, emphasizing the role of robust supply chain structures in mitigating the effects of any unplanned events that can cause negative consequences. The authors further write that complex supply chains are typically more susceptible to disruptions due to their extended global reach and that these complex supply chains particularly benefit from enhance visibility. This improved visibility allows for better risk management and as a result contributes to the robustness of the supply chain by enabling quicker and more accurate responses to disruptions.

2.2.3 Supply Chain Visibility

The supply chain consists of different actors including suppliers, manufacturers, distributors and consumers (Bartlett, 2007). Supply Chain Visibility involves timely access to accurate information across a supply chain between different relevant actors (Somapa, et al., 2018).

Supply Chain Visibility according to Saqib et al., 2020, is one of the most valuable terms in supply chain management, offering companies and their customers actionable information about their supply chain orders in real time. With advancements in technology, Supply Chain Visibility now includes a broader range of data to better understand current conditions and their impact on operations (Saqib et al., 2020).

Improved visibility is recognized as a crucial element in mitigating supply chain risks (Durach et al., 2015). The article approaches visibility from a relational and network structure (Durach et al., 2015). Relational aspects between different supply chain actors are highlighted in the study, suggesting that efforts in enhancing visibility through risk related information sharing lead to increased risk avoidance (Durach et al., 2015). Compatible IT infrastructures play a vital role in facilitating information exchange among partners (Durach et al., 2015).

According to Brandon et al., 2014, visibility serves as the primary link between a company's resources and its performance output. These resources encompass supply chain connectivity, representing a company's tangible assets essential for sharing information across the supply chain, typically facilitated by information systems and IT infrastructure (Brandon-Jones et al., 2014). Information sharing, another critical resource, is described as timely, accurate, relevant, and confidential (Brandon-Jones et al., 2014). Together, these resources contribute to a firm's capabilities, culminating in visibility (Brandon-Jones et al., 2014). Visibility, in turn, drives a company's performance, ultimately benefiting supply chain resilience and robustness as it reduces the likelihood and impact disruptions and enables organizations to identify and mitigate risks proactively (Brandon-Jones et al., 2014).

Fraser et al., (2020) discuss in their article that achieving visibility in supply chains is increasingly challenging across various industries, particularly in the automotive industry. They highlight that while some sectors have seen significant research into multi-tier supply chain visibility and achieved a degree of transparency, industries dealing with specific minerals face greater complexities with the automotive industry being one of them.

In addressing the challenges of achieving effective supply chain visibility, particularly in complex environments such as the automotive industry, (Fraser et al., 2020) emphasize the importance of integrated technological systems and collaborative communication strategies across all tiers of the supply chain. They argue that integrating advanced tracking and analytical tools, such as IoT devices and AI driven analytics, can significantly enhance the depth and quality of visibility. These technologies help in real time monitoring and predictive analysis, enabling companies to anticipate disruptions and adjust operations dynamically. This proactive approach not only enhances operational efficiency but also strengthens the entire supply chain's adaptability to

external pressures and changes, underscoring the critical role of technological advancement in achieving and maintaining high levels of supply chain visibility.
However, much of the research on the benefits of supply chain visibility remains theoretical, with many studies focusing on only a subset of performance indicators and often only examining dyadic relationships between the different included actors in the supply chain. Moreover, there is limited research on visibility involving upstream supply chain actors or on the benefits of sharing information beyond sales and demand forecasts, such as order status or production plans. Thus, while the advantages of improved visibility in supply chains are recognized there is still a need for more comprehensive empirical evaluations to fully understand its potential benefits. (Caridi et al., 2014)

Benefits regarding Supply Chain Visibility

Supply Chain visibility primarily aims to enhance the company's performance by supporting decision making processes. Initiatives such as Quick Response, Efficient Consumer Response, Vendor Managed Inventory, and Continuous Replenishment have successfully integrated visibility to improve performance metrics like cost, quality, service level, flexibility, and time. Visibility enables better information sharing between different actors, both upstream and downstream, in the supply chain which in turn can lead to significant reductions in inventory and cost savings for instance. (Caridi et al., 2014)

Enhanced management of disruptions

Supply chain visibility (SCV) is crucial for mitigating disruptions within the supply chain, a point underscored by various researchers and incidents (Yu and Goh, 2013). SCV involves the capability of a supply chain participant to access or provide essential information in a timely manner to and from relevant partners, which supports better decision making and operational efficiency (Yu and Goh, 2013) .
Key benefits of enhanced supply chain visibility include:

- Improved Operational Efficiency: Good visibility helps in streamlining operations and enhances the efficiency of supply chain planning. For example, sharing point-of-sale (POS) information across the supply chain can significantly reduce the bullwhip effect, a phenomenon where order variances increase up the supply chain (Yu and Goh, 2013).
- Risk Mitigation: The text highlights how visibility can reduce the impact of supply chain disruptions. For instance, during the 2011 earthquake and tsunami in Japan and the flooding in Thailand, the automotive and electronics industries felt significant impacts due to disruptions in parts supply. Enhanced visibility could have potentially minimized these disruptions by allowing companies to better manage and adjust their supply chains in response to emerging risks (Yu and Goh, 2013).
- Proactive Management of Disruptions: With higher visibility, companies can proactively manage risks by having advanced knowledge of potential supply issues and therefore can strategize on alternative sources or methods to fulfil demand. This proactive approach is critical especially when dealing with single-source suppliers or suppliers in high-risk regions (Yu and Goh, 2013).
- Technology and SCV Enhancement: Technologies like RFID and advanced data analytics tools like Power BI are instrumental in enhancing SCV. They enable real-time tracking and sharing of information, which is vital for managing the supply chain dynamically and responsively (Yu and Goh, 2013).

- Strategic Supplier Selection: The visibility into operations and supplier performance helps companies make informed decisions when selecting suppliers. This decision making process involves balancing cost, risk, and visibility to ensure a resilient supply chain (Yu and Goh, 2013).

In conclusion, supply chain visibility is a pivotal factor in managing and mitigating disruptions in the supply chain. It facilitates better operational control, risk management, and strategic decision making, ultimately contributing to a more stable and efficient supply chain network (Yu and Goh, 2013).

2.2.4 Categorizing Disruptions

Craighead et al. (2007) provide a comprehensive framework for evaluating supply chain disruptions, emphasizing the importance of categorizing the severity of disruptions to better understand their effects on the supply chain. The categorization promotes the kind of nuanced analysis of each disruption event in a way that enables targeted responses and resource allocation.

Similarly, Tang (2006) points out the need to recognize and evaluate supply chain risks. A categorization based on disruption impact will allow the organization to use more accurate and effective mitigation strategies. This approach not only helps with the efficient management of current disruptions but also with preparing for future risks and as a result enhancing overall supply chain resilience.

Informed by these studies, it is possible to construct a disruption severity scale that grades the impact of each event from minimal to critical. Such a scale would allow for a systematized analysis of the disruptions, be they the Covid-19 outbreak or natural disasters, for clarity on their intensity and the development of strong strategies to mitigate their effects on the supply chain.

3. Methodology

This section of the study outlines the methodology employed in conducting the research. Firstly, it introduces the Research Question Formulation, detailing the development of the study's purpose and specific research questions. Secondly, the Case Study approach is explained, focusing on the chosen case company. Thirdly, the Data Collection Methods are outlined, including interviews, literature review, and secondary data analysis. Finally, the methodology addresses the Quality Discussion, examining the study's credibility through validity, reliability, and triangulation. This structured approach ensures a comprehensive investigation of the research topic.

3.1 Research Question Formulation

The research question formulation is an important step in the research process, marking the beginning of the study by defining its purpose and specific research questions. As outlined by Hair (2015), this phase requires a deep understanding of the problem at hand, emphasized by a thorough review of existing literature to gain insights and establish clear objectives. Further, Sekaran and Bougie (2016) highlight the importance of crafting specific, relevant research questions that align with the study's objectives, which was the approach taken by the authors.

The authors followed a structured approach to formulating the research questions in detail. Starting with an extensive literature review, they immersed themselves in a large quantity of academic sources, including papers, books, and reports, to enrich their understanding of the research area (Hair, 2015). This comprehensive literature review was essential to identify gaps in existing knowledge, theoretical frameworks, and to provide a solid foundation for the study.

In addition to the literature review, preliminary interviews with internal stakeholders were conducted to delve deeper into the topic's details, as advocated by Bell et al., (2022). These interviews provided practical insights that complemented the theoretical understanding gained from the literature. Drawing from these insights, the authors formulated specific research questions that guided the study's direction, ensuring alignment with the underlying goals and the identified needs (Bell et al., 2022).

This rigorous groundwork, combined with the establishment of clear objectives, laid a strong foundation for the subsequent phases of data collection, analysis, and interpretation. By following this practical approach, the authors ensured that the research questions and objectives were sharply defined and effectively addressed. This comprehensive process, as explained in the literature, enabled the authors to methodically navigate the complexities of the research phase and set the stage for a robust and insightful study.

3.2 Case Study

A case study is an ideal method for this investigation because it allows for an in-depth exploration of contemporary phenomena within their real-life context (Yin, 2018). This approach is particularly suited for this research report as it aims to answer the "what" and "why" of a given phenomenon (Saunders et al., 2019). Therefore, using a case study in conjunction with well formulated research questions is optimal for investigating the measures implemented over time during a crisis.

The case company, Company A, is a global leader in providing transportation solutions, specializing in manufacturing, mainly trucks and heavy transport applications. Company A also offers insurance and rental services, allowing customers to streamline their operations.

Operating in a large quantity of countries, where an extensive workforce is spread, Company A has a significant international presence that ensures they are accessible to

clients all over the globe. The company has concentrated its research and development efforts in one country, while the core manufacturing takes place in two different continents.
Company A emphasizes strong partnerships and cooperative strategies in its business approach. This includes the building and maintenance of long-term relationships with a broad network of stakeholders in the transport and logistics sectors, which will help promote sustainable transport. The company is committed to improving the sustainability performance within the whole supply chain and aims to increase the transparency and cooperation with suppliers for overall sustainability performance.
Regarding Company A's procurement operations, it has a large team of purchasers, handling a vast network of suppliers around the world, and a central team at the headquarters to ensure alignment with their purchasing strategies and purchasing operations. A significant portion of that was direct purchasing of products that are necessary for them, such as components with semiconductors.

3.3 Data collection

In this research, the authors employed a comprehensive data collection strategy that included qualitative methods to ensure a thorough investigation of the research questions. The group aimed to capture a wide range of data, providing both depth and breadth to the analysis. Specifically, the writers utilized interviews to gain in depth insights from various stakeholders. Also, including the analysis of secondary data from the case company and reports online, helped to identify patterns and relationships in the details regarding measures and disruptions. This mixed methods approach allowed the group to triangulate the findings, enhancing the validity and reliability of the research.

3.2.1 Interviews

The research group utilized qualitative interviews as the primary method of data collection to address the research questions outlined in this report. Influenced by Flick et al. (2004), which covers various forms and methods of qualitative interviews and provides helpful guidelines on their application, the authors conducted interviews with internal employees at Company A. The book by Flick et al. (2004) describes a range of qualitative interview variants commonly used in research. These include open interviews, focused interviews, narrative interviews, problem-centred interviews, and episodic interviews. Each method is characterized by its unique way of questioning, its level of structure, and its focus on specific themes or topics. The authors used three of these strategies regarding the research project, which are explained below.

Qualitative Research Methods
Qualitative research employs various methods to explore and gain knowledge of complex occurrences, often in-depth and from multiple perspectives (Bell et al., 2022). In this study, the authors considered several qualitative research methods to investigate the research questions effectively.

Ethnography and Participant Observation
This method involved prolonged engagement within the company and the different departments to observe and participate in their activities, aiming to uncover rich insights into their culture and practices (Bell et al., 2022). The authors partook in weekly meetings with a team within the company to establish a deeper understanding of the topic. These meetings provided valuable opportunities to deepen insights and refine the research focus through direct engagement with relevant internal stakeholders at the case company. Further, the group had regular follow-up meetings with the management in order to fact check the information that had been acquired during the interviews. The

authors established presentations on certain topics gathered from the interviews and presented it to personnel that could revise the information further enhancing the validity of the interviews.

Qualitative Interviewing

Qualitative interviews, which can be open-ended, semi-structured, or in depth, facilitated one-on-one conversations with participants, allowing for a detailed exploration of individual experiences and perspectives (Bell et al., 2022). The authors performed interviews with relevant internal actors, providing valuable insights from diverse perspectives, enhancing the understanding of the research topic, and contributing to a comprehensive analysis.

The different methods that were used during the qualitative interviews were, *Open interviews*, also known as semi-structured interviews, involve a flexible approach where the interviewer has a general set of topics but allows for the discussion and exploration of other ideas and subjects (Flick et al., 2004). This method, supported by Rubin and Rubin (2011), emphasizes the importance of open questions to encourage interviewees to express their thoughts and feelings freely, leading to an in-depth exploration of participant perspectives and potentially uncovering crucial study topics that might not surface in fully structured interviews.

The group also utilized *narrative interviews*, following the method outlined by Flick et al. (2004). These interviews, often used in history or life story questions, aimed to have interviewees generate their narratives. During these interviews, the authors adopted a passive role, acting as attentive listeners to support the interviewee's storytelling. Follow-up questions were used strategically to steer the narrative towards specific phases, situations, or arguments, diving deeper into the interviewee's experiences and perspectives.

One of the methods the authors employed was the *focused interview*, as described by Flick et al. (2004), which originated in communication research. In the last stage of qualitative interview data collection, focused interviews were used to concentrate on pre-selected topics, such as specific events causing disruption, measures, or workplace dynamics. The objective was to collect responses and interpretations transparently, allowing interviewees to share their opinions on specific matters. This method ensured a comprehensive understanding of the interviewee's perspectives by emphasizing the scope.

The three methods were implied during different stages of the interview process. The first stage, using open interviews, allowed the interviewees to speak freely about the situation over the past couple of years. The introduction and first stage of the interview were with experienced people who either had worked for Company A for a long time or had a direct involvement in the Task Force. They were the perfect candidates to grasp the crises and events happening during that time. This helped the interviewers later during the second stage of the interviews. The stakeholders were chosen more specifically towards specific topics, events, or actions that were taken. The interviewers used narrative interviewing to get more specific answers to their questions. Lastly, the third stage was only focused interviews regarding specific topics. In table 1, it is shown the different stages under the four month duration of this study. The interviewees starting with AX are the stakeholders that were part of the dedicated semiconductor team after the crises and worked actively on that topic. The others starting with only A are relevant stakeholders that were a part of the crises in specific areas.

Sign	Position	Duration	Method
Introduction stage			
AX1	Purchaser	60 min	Open Interview
AX3	Senior Purchaser	60 min	Open Interview
AX5	Manager Commodity Purchasing	30 min	Open Interview
First Stage			
A7	Procurement Advisor	60 min	Open Interview
A1	Shortage Manager	50 min	Open Interview
A2	Senior Purchaser	60 min	Open Interview
A3	Senior Purchaser	40 min	Open Interview
AX1	Purchaser	30 min	Narrative Interview
AX3	Senior Purchaser	30 min	Narrative Interview
AX4	Buyer	30 min	Focused Interview
Second Stage			
A4	Supplier Escalation Manager	50 min	Narrative Interview
A5	Supplier Shortage Manager	40 min	Narrative Interview
A6	Procurement Advisor	40 min	Narrative Interview
AX1	Purchaser	30 min	Focused Interview
AX3	Senior Purchaser	60 min	Focused Interview
AX2	Purchaser	30 min	Focused Interview
Third Stage			
A8	Supply Chain Risk Manager	35 min	Focused Interview
A9	Supply Chain Risk Manager	35 min	Focused Interview
AX1	Purchaser	30 min	Focused Interview
AX2	Purchaser	60 min	Focused Interview
AX3	Senior Purchaser	30 min	Focused Interview

Table 1, Table of interviewees

Focus Groups

This method involved group interviews led by a moderator, where participants engaged in discussions on specific topics, fostering interactions that revealed diverse viewpoints, shared experiences, and group dynamics (Bell et al., 2022). The authors conducted focus group interviews to efficiently gather insights during their time at the case company. This approach allowed for the simultaneous gathering of insights from multiple participants, increasing the understanding of the research topic. The attendees of the focus groups consisted of the team that was assigned to the group when they initially started the study with Company A. These meetings were held once every week in order to understand the topic and the evolution of the measures continuously.

3.2.2 Literature Review

In the initial stage, the authors defined the study's purpose, identified research questions, and established clear objectives as mentioned previously. As outlined by Hair (2015), this phase required a deep understanding of the problem at hand, emphasized by a thorough review of existing literature to gain insights and establish clear objectives. Further, Sekaran and Bougie (2016) emphasized the importance of crafting specific, relevant research questions that align with the study's objectives, an approach the authors adopted.

In this report, the authors followed this structured approach in detail. They began with an extensive literature review, immersing themselves in academic sources, including papers, books, and reports, to deepen their understanding of the research area (Hair, 2015). Concurrently, preliminary interviews with internal stakeholders were conducted to delve deeper into the topic's details, as advocated by Bell, et. al., (2022). Drawing from these insights, the authors formulated specific research questions that guided the study's direction, ensuring alignment with the underlying goals with the literature standing as a base for the interviews.

During the execution phase, the authors continued with the comprehensive literature review to gain deeper insights into the research topic, identify theoretical frameworks, and highlight gaps in the existing literature (Hair, 2015). This step was crucial in framing the study within the broader academic context and ensuring that the research was grounded in established knowledge while addressing unexplored areas.

The literature review served as a preliminary step that significantly increased the authors' knowledge of the subject, enabling the development of relevant and insightful research questions for the subsequent interviews with the internal stakeholders of Company A. These interviews targeted key personnel within the company to cover a wide range of perspectives, further enriching the study's data.

Moreover, the literature review helped in categorizing the identified measures and disruptions. This categorization, based on insights from the literature, clarified the results and provided structure for the analysis. It ensured that the findings were coherent and systematically presented. Further, the literature review provided an insight in regard to the different categorizations of measures over time and their relation to flexibility and robustness.

3.2.3 Secondary data

Secondary research involves gathering data that already exists through various sources such as databases, reports, and internal documents. This approach provides context and supplements the primary research findings (Johnston, 2014). Researchers often use secondary data from different sources to enhance their understanding of the topic (Babbie, 2016). In this research report, the group utilized secondary data in symbiosis with qualitative methods, drawing on documents acquired from the case company. This secondary data served as a foundation for understanding the topic and provided valuable insights into the research questions, supporting the overall research framework.

The data, contained historical records and internal documents that gave insight into the company's past and current operations in regard to the crisis that occurred. Therefore, through the use of this secondary data, the authors were able to support their findings from the interviews and the literature review in a way that develops a comprehensive understanding of the supply chain disruptions and measures adopted during uncertain times. The events that occurred and the timeline of the adopted measures were mostly acquired from secondary data during this analysis. The use of Company A's existing data allowed the authors to validate their empirical findings and to deepen the analysis, making the overall findings more robust and credible. Further, the internal documents

supported the authors in establishing the scale of the impact the disruptions had on Company A.

3.2.4 Data Analysis

The group utilized the Gioia Methodology, a qualitative approach that provides a framework for coding and analyzing data, enabling the authors to uncover detailed insights and patterns within the qualitative data (Magnani & Gioia, 2020). This methodology facilitated systematic coding of the gathered data, enhancing research rigor and grounding conclusions in empirical findings.

In conducting qualitative research, the Gioia Methodology (table 2) begins with capturing interviewees' understandings of their experiences. These statements were systematically collected from interviews and other data sources, starting with open coding to allow for the emergence of numerous categories based on the interviewees' narratives (Magnani & Gioia, 2020). The researchers then reduced the initial set of comments to a manageable number by merging similar comments in the same category through constant comparison, resulting in a set of second-order codes that were more abstract.

Following the creation of a robust data structure, theoretical models illustrating the relationships among the emergent measures were developed. These models included timelines, organizational impact aspects, and frameworks for enhancing flexibility or robustness, guiding readers' understanding and outlining the main findings (Magnani & Gioia, 2020).

Depending on qualitative or quantitative nature, the analysis methods varied. Qualitative studies required the identification of themes or categories, resulting in a detailed report that communicated the research findings, conclusions, and recommendations (Hair, 2015). Various methods can be employed to understand collected data and uncover patterns during the analysis stage (Hair, 2015). Once the data was analysed, the authors integrated the results, identified key insights, and evaluated the implications for addressing the research questions (Bell, et. al., 2022). However, during this study the authors used a qualitative approach which was supported by interviews and secondary data in regard to the data analysis.

Further, categorizing the identified measures and disruptions, based on insights developed during the literature review, helped to clarify the results and provide structure for the analysis. This categorization placed the measures and disruptions in context, aiding in understanding their impact and relevance.

The overall practical approach of the study was a well coordinated, systematic process, from defining the research scope to carrying out a literature review, conducting interviews, and analyzing the data gathered by the authors and secondary data provided by Company A. This comprehensive approach ensured that the findings were sound, complete, and contributed new knowledge concerning supply chain disruptions and the measures taken within the automotive industry.

First order concept	Second order theme	Measures	Approach
A Taskforce team was created to fully focus on events that caused disruption within the supply chain of any kind and affected the production. The Taskforce had also a close relationship with the bigger company that Company A is a part of to stress the bigger issues. (A1, Shortage Manager, personal communication, 2024)	During the semiconductor crisis, there was a need to manage supply chain disruptions, fostering close ties with sister companies and semiconductor manufacturers. To improve the cross-functional working and leveraging expertise to mitigate impacts a dedicated team was necessary. centralize information, and enhance flexibility and collaboration	Taskforce	Flexibility

	across departments, ensuring continuity and effective problem-solving.	
Early on during the crises the Taskforce was created, which I was a part of. Having the expertise and the insights from others in the Taskforce, we could evaluate and decrease the impact of the disruption in different departments, especially focusing on the more crucial once. (A2, Senior Purchaser, personal communication, 2024)		
It has been interesting as mentioned, this thing with the crisis, it has been tough but very developmental I think for Company A to find new ways but also Company A as an organization has always been flexible and adapted quickly and found solutions. The Taskforce that was created, where we worked together cross-functionally and also very good contact with R&D also where you can discuss solutions. (A2, Senior Purchaser, personal communication, 2024)		
The Digital Component Catalogue is still in use, which was something that existed before the crisis but was further developed during the crisis. I'm not sure if it was the Taskforce team that established this measure or if it was developed before them, but I remember there was a lot of focus on centralizing all information and working more cross-functionally. (A4, Supplier Escalation Manager, personal communication, 2024)		
During covid and shortage of crucial components, technical changes were necessary. for example, using replacement components to get the production going. (A1, Shortage Manager, personal communication, 2024)	Implementation of technical changes, such as using replacement components to maintain production, conducting post-market campaigns to retrofit missing components, leveraging digitalization for better exploration in alternative sourcing options to mitigate material shortages and ensure supply chain continuity.	Alternative Component
While some suppliers were hesitant to engage directly with manufacturers, others actively provided alternative suggestions for components. (A5, Supplier Shortage Manager, personal communication, 2024)		
The impact of digitalization on supplier relations and the need for close monitoring of supplier locations and alternative sourcing options due to potential material shortages. (A9, Supply Chain Risk Manager, Personal communication, 2024)		
Another short-term measure was including top management in supplier/manufacturer meetings to stress the issues. (A1, Shortage Manager, personal communication, 2024)	Meetings with top management to expedite decision-making and included top management in supplier and manufacturer meetings to emphasize the urgency of issues and ensuring effective crisis management.	Management Involvement
Daily meetings with top management were effective in making quick decisions to address crises. (A6, Procurement Advisor, personal communication, 2024)		
Some of the decisions and bigger purchases	A flatter hierarchy allows team	Flat

normally would have to go through different hierarchy levels to get approved, but during the crises the team managers and some other employees could make decisions on their own. Judging the situation, make the best purchase to prevent production stop. Meaning a flatter hierarchy within the organization during that specific time, another short-term measure. (A1, Shortage Manager, personal communication, 2024)	managers and employees to make significant decisions and purchase autonomously to prevent production stoppages. This streamlined decision-making process was a short-term measure, with plans to revert to the standard hierarchy post-crisis.	Hierarchy	
This thing with broker buys, it was like it could be taken at a very flat level so to speak, the sums that were bought there, normally go through some approvals from the managers. Just that thing with broker buys, you almost had to decide in a few hours whether to buy or not buy and then you couldn't have long escalation chains, then it was like you got the mandate to make the decisions yourself or at the group manager level. Usually, it worked well, and we saved many deals on that. (A2, Senior Purchaser, personal communication, 2024)			
Flatter hierarchy under the crisis, but after the crisis is done back to normal business. (A3, Senior Purchaser, personal communication, 2024)			
During the crises it was necessary to work more cross-functional within each team and different departments. We realized, this is a success factor in overcoming various challenges. Faster information sharing and decision making as mentioned earlier. This measure was also helpful regarding other challenges that had nothing to do with semiconductors. Realizing we need to work together and include right competence for better and faster decision making regarding everything. (A1, Shortage Manager, personal communication, 2024)	During the crisis, collaborations involving representatives from different departments for better decisions and solutions were crucial. This approach helps with faster information sharing and decision-making, proving essential not only for semiconductor-related issues but also for overcoming various other challenges	Intensified Cross-functional Working	Robustness
It has been interesting as mentioned, this thing with the crisis, it has been tough but very developmental I think for our company to find new ways but also the organization has always been flexible and adapted quickly and found solutions. The Taskforce was created, where we worked together cross-functionally and very good contact with R&D also where you can discuss solutions. (A3, Senior Purchaser, personal communication, 2024)			
Collaborative problem-solving efforts, indicating the effectiveness of assembling cross-functional teams to tackle complex issues. (A8, Supply Chain Risk Manager, personal communication, 2024)			
One initial measure was Company A's 12 month forecast but some of them have a longer production cycle. This led to extending the forecast and implementing a 24 month forecast method to make sure the suppliers are aware of Company A's needs for the future. (A1, Shortage Manager, personal communication, 2024)	To ensure that the suppliers were informed of future needs, Company A extended its forecasting period from 12 to 24 months for components that were more critical.	Longer Forecasting	
We have also established a longer forecast process. Previously, we only sent out 12-month forecasts for products, but now we send out 24			

months for those with semiconductors simply because the lead times are so long. For many of these components, it's a year or more, and then it's important to have long-term forecasts. (A2, Senior Purchaser, personal communication, 2024)		
Efforts were made to prolong forecasts for critical components to mitigate the impact of global shortages. (A5, Supplier Shortage Manager, personal communication, 2024)		
Before the crises Company A used the Just-In-Time strategy for their production. Both for economical reason and difficulties to maintain storages. So another measurement we applied was building buffers for components that are critical for the production, post-shortages when we had enough components for the production. (A1, Shortage Manager, personal communication, 2024)	Shifting from a Just-In-Time strategy to building buffer stocks for critical components. This involved careful commercial negotiations to decide whether to build or outsource these buffers.	Strategic Buffering
To decide whether Company A builds the buffer or outsource it, is a commercial negotiation where different options need to be compared and analyzed. (A1, Shortage Manager, personal communication, 2024)		
We have had buffer stocks at Company A for certain important electronic products during the past year, mostly components containing semiconductors. (A2, Senior Purchaser, personal communication, 2024)		

Table 2, Illustration of how the group conducted the Gioia Methodology.

3.4 Quality Discussion

In the methodology discussion, the authors will emphasize validity, reliability, credibility, and triangulation to ensure robust research outcomes. Validity ensures accurate measurement, including both internal and external aspects to ensure applicability beyond the specific context of the study. Reliability guarantees consistent and reproducible findings, critical for dependable research outcomes. Credibility is established through transparent and rigorous research methods, ensuring the study's trustworthiness. Triangulation involves integrating various different data sources to enhance validity and rigor, minimizing biases and benefiting the reliability of findings. Through this multifaceted approach, including various data collection methods aligned with established frameworks, the authors aim to construct a solid research foundation and produce credible and reliable outcomes.

3.4.1 Validity

Validity is a critical aspect of the group's research methodology, ensuring that the study accurately measures what it intends to measure and produces credible and reliable results (Bryman & Bell, 2015). Validity refers to the extent to which the group's findings accurately reflect the underlying reality being studied. The authors addressed two main aspects of validity: internal and external validity. Internal validity concerns the extent to which the observed effects in the study can be attributed to the variables being measured, rather than to biases. External validity refers to the generalizability of the research findings beyond the specific context of the study. It assesses whether the results obtained from the group's samples can be extended to the larger population or other settings (Bryman & Bell, 2015). Essentially, internal validity ensured that the study accurately reflected what was intended to be studied, while external validity ensured that the findings could be applied to other situations (Bryman & Bell, 2015).

3.4.2 Reliability

Reliability refers to the extent to which the groups research findings are consistent and reproducible. It involves ensuring that the research methods that were used are dependable and provide consistent results if the study were to be repeated under similar conditions (Bryman & Bell, 2015). The group assessed reliability through the consistency of results when the study is repeated over time, the consistency of results when different researchers analyze the same data, and the consistency of results across different items within the same measurement approach (Bryman & Bell, 2015).

3.4.3 Credibility

Credibility in the groups research is established by demonstrating the reliability and validity of the findings. It involves ensuring that the study is conducted with integrity, transparency, and adherence to established research standards (Bryman & Bell, 2015). The authors enhanced credibility through rigorous data collection and analysis methods. Essentially, credibility refers to the confidence that readers can have in the accuracy and trustworthiness of the groups research findings (Bryman & Bell, 2015).

3.4.4 Triangulation

Triangulation enhances the rigor in theory building, it emphasizes using multiple types of data from various sources to increase confidence in the accuracy of the constructs identified (Kathleen & Eisenhardt Timothy , 2017). Triangulation helps to ensure that the emergent theory is compellingly grounded in data, enhancing the study's overall rigor (Kathleen & Eisenhardt Timothy , 2017). Triangulation further enriches research validity by countering bias from single sources, contributing to both internal and external validity (Farquhar et al., 2020). To further enhance the rigor of the study through triangulation, the researchers will first define compelling and relevant research questions (Turner et al., 2017). Next, the authors will determine their theoretical intentions as per the article written by Turner et al., 2017.

To increase the study's validity, the authors will employ a multifaceted approach to triangulation. This will include an in-depth examination of internal documents produced by the case company, which provides a direct insight into the topic at hand. Additionally, an extensive literature review will be conducted to ensure a comprehensive understanding of the existing theoretical frameworks and empirical findings related to the research topic. This literature review aims to situate the current research within the broader academic discourse, identifying gaps and aligning the study's objectives with the field's needs. Lastly, interviews will be carried out as a primary data collection method. These interviews are designed to gather qualitative insights from individuals directly involved in or knowledgeable about the research subject. This triangulation strategy, combining document analysis, literature review, and interviews, aims to construct a robust and valid research foundation, minimizing biases and enhancing reliability of the findings. As for the research questions and theoretical intentions the authors will follow the framework established in the beginning of the methodology.

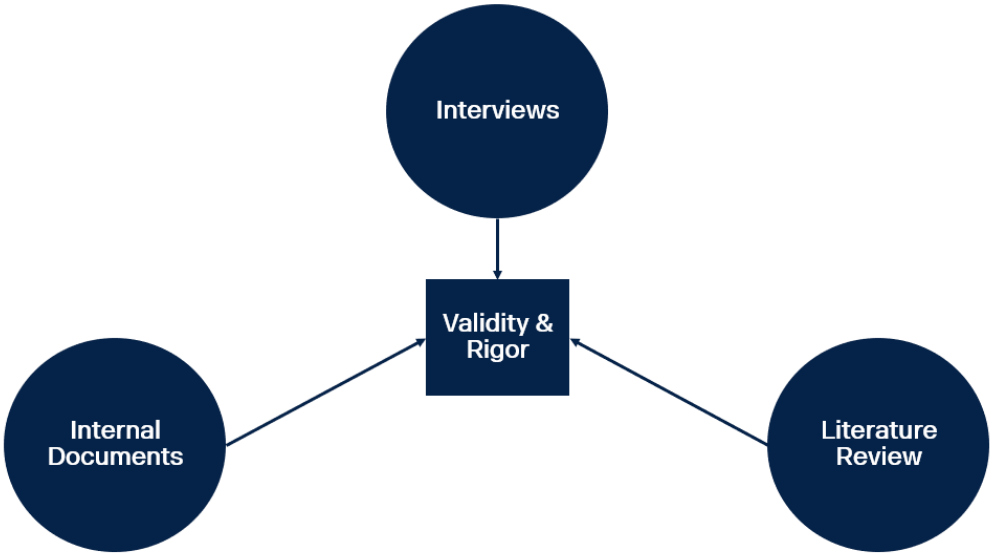

Figure 4, Triangulation Process, (Eisenhardt & Ott, 2017)

4. Empirical Findings

This chapter aims to present the findings obtained from interviews conducted with representatives from each department, offering valuable insights into the disruptions that have accrued during the past few years which led to the crises and how the organization responded to the semiconductor shortage. The chapter is divided into two sections, starting with the disruptions and moving to describe and analyse the measures.

Thanks to the case company, the group had the opportunity to develop a deep understanding of the strategies employed by the purchasing department in response to the disruptions both causing semiconductor shortage and caused by the shortage. This exploration provided a comprehensive understanding of the events leading to disruption and how the purchasing department and the organisation navigated through the challenges posed by the shortage. The information gathered clarified the strategies used by different parts of the organization. From procurement to inventory management, each department had the opportunity to have an input and develop strategies tailored to address the specific disruptions encountered.

4.1 Disruptions

The chart 1 captures events such as the onset of the Covid-19 outbreak, natural disasters, fires and other significant incidents that disrupted supply operations of semiconductors during the crisis. Each disruption is assessed based on its impact, ranging from minimal to critical, providing a clear understanding of the severity of each event. The X-axis represents the timeline, while the Y-axis notes the scale of disruption impact which is defined as such:

Disruption severity scale

1. **Minimal Impact**: Potential disruption that caused attention but no delays for tier 1 suppliers or minor delays to tier 1 delivery but no impact on the case company's production.
2. **Moderate Impact**: Recognizable disruption with delays or shortage of components that requires action taken to mitigate the impact of disruption. No impact on the case company's production.
3. **Severe Impact**: Disruption prompting production adaptability e.g. adjustment in production due to missing components.
4. **Critical Impact**: severe disruption e.g. case company's production Slowdown due to missing components.

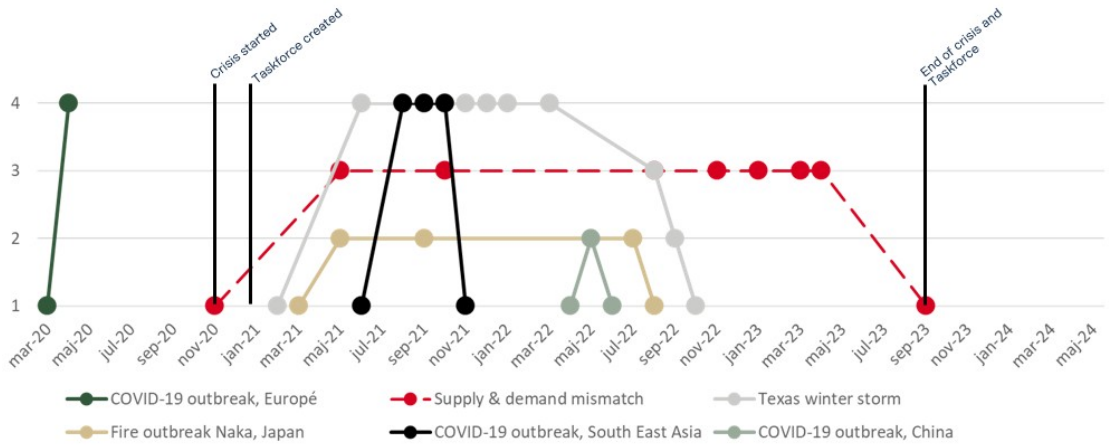

Chart 1, Timeline of most impactful supply chain disruption events

Additionally, the chart highlights the start and end dates of the crises, offering a timeline overview of the disruptions faced. Moreover, it outlines the implementation period of key measure, the establishment of the Taskforce, which was a pivotal response to add a lot of flexibility to mitigate the effects of semiconductor shortage during the crises. This empirical visualization serves as a valuable reference point for analysing the timing of disruptions and the corresponding measures adopted in response. Also, it is important to address that each dot in the beginning of the line marks the recognition of the event. further the dot at the end of each line marks the date when the event didn't have any effect on the production anymore, meaning no delays or shortages. The chart illustrates various dots during the time period of each event representing the consequences of these events, indicating different impacts such as delays or shortages of semiconductor chips and the effect on the semiconductor supply chain, providing a visual timeline of the crisis.

The first disruption to the semiconductor supply chain occurred in March 2020 with the COVID-19 outbreak in Europe. This unprecedented event led to immediate shutdowns of company's production across different countries as governments implemented measures to curb the spread of the virus. These actions had a big impact on the manufacturing sector, including the semiconductor industry, leading to a rapid escalation in disruption severity. Initially considered a potential disruption, the situation quickly escalated, reaching a critical impact level scale 4 when company A's production was stopped.

Sometime after the companies started to resume operations, they started to notice even more impactful situation emerge. By November 2020, substantial supply and demand mismatch in the semiconductor market caused by the first disruption started to appear. The main reason for this mismatch came from a huge spike in demand for semiconductors across various industries. The global effect of shifting work and learning to a remote platform brought with it an increase in demand for electronic devices like computers, monitors, televisions and smartphones. Households around the world were upgrading their technology for home offices and virtual classrooms, all of which heavily rely on semiconductors. This supply and demand mismatch quickly escalated to a severe impact level scale 3, creating a significant strain on the entire semiconductor supply chain. The shortage of critical components led to delays and disruptions in various industries, from consumer electronics to automotive manufacturing. This supply and demand mismatch marked the start of a semiconductor crisis, which started in end of 2020. The crisis became one of enduring shortages, extended lead times and elevated costs for semiconductor components. Manufacturers found themselves having to make key decisions about short-term needs for components.

Following the onset of the crisis, the Taskforce was quickly assembled, playing a pivotal role in responding to the numerous challenges that emerged. The main purpose of the Taskforce was to mitigate the severe effects of the disruptions on production and keep continuity in the supply chain. Their strategic and coordinated efforts were indispensable in negotiating the complex landscape of semiconductor shortages.

Next in February 2021, the winter storm that happened in Texas created another significant disruption to the semiconductor supply chain. This event had a critical impact, reaching a severity level of scale 4, due to its high effect on the supply of specific semiconductor chips that were essential for Company A's production processes. The effects of this storm continued to impact the supply chain with fluctuations and periodic shortages until November 2022. Throughout this period, Company A repeatedly faced shortages of critical semiconductor chips, necessitating the implementation of various measures to mitigate these ongoing challenges.

Following the Texas winter storm, another disruption occurred due to a fire outbreak at a semiconductor manufacturer in Japan. This event reached a high impact level, its consequences were still significant and lasted until September 2022. The fire caused

damage to the manufacturing facilities, leading to delays and reduced production capacity for several types of semiconductor chips. The components affected by this fire, while important, were less critical to Company A's production compared to those impacted by the Texas winter storm. This relative non-criticality, combined with the measures already in place from dealing with previous disruptions, helped minimize the impact on overall production. The fire in Japan prompted Company A to continue leveraging the radical measures they had previously implemented, such as sourcing alternative components and using the broker market to fill in supply gaps. Additionally, the company intensified its efforts to ensure that they could quickly adapt to any changes in the supply landscape.
The chart also captures the COVID-19 outbreak in South East Asia, which affected several the semiconductor manufacturers. This outbreak led to severe impact, scale 4, including production slowdown. However, over time, Company A resumed production at a reduced capacity. Lastly, another COVID-19 outbreak in China is shown on the chart. This event, while significant, had a more moderate impact, scale 2.
In summary, chart 1 illustrates five key disruption events, the initial COVID-19 outbreak in Europe, the Texas winter storm, the fire in Japan, the COVID-19 outbreak in South East Asia, the COVID-19 outbreak in China and one significant consequence of the first COVID-19 outbreak in Europe, the supply and demand mismatch. These events are critical in understanding the semiconductor shortage crisis and the measures taken by Company A to mitigate the impacts on production. The timeline provided by the chart offers a view of the disruptions and the strategic responses that helped navigate through the crisis.

4.2 Measures

In this section of the report, the authors will explore the various measures implemented by Company A to mitigate the consequences of disruptions.

4.2.1 Adopted Measures

By measures, the authors refer to specific actions taken by the company to address the challenges posed by unforeseen events or crises. It's important to note that these measures include a wide range of strategies, from preventive planning to immediate responsive actions, aimed at minimizing the impact of disruptions on production and business operations. Further, a measure may involve the utilization of existing resources within the company, but exploited more efficiently or strategically during times of crisis. Through a detailed examination of these measures, the writers aim to provide insights into Company A's disruption response measures and their effectiveness in navigating disruptive events.
Viewing table 3, the measures are present and defined. Further, a more specific definition of each measure can be found in Appendix 1.

Measure	*Definition*
Taskforce	Dedicated team assembled to address the semiconductor shortage crisis
Dedicated Semiconductor Team	A dedicated team for semiconductor issues and challenges, developed post-crises
Alternative Components	Leveraging substitute parts to continue production when original parts are unavailable
Broker Market Scouting	Sourcing components from the broker market as a last resort measure during shortages
Management Involvement	Increased participation of internal management in daily operations to ensure quick decision making and problem solving
Flat Hierarchy	Reducing organizational layers to speed up communication and decision making processes

Intensified Cross-functional Working	Establishing collaboration between various departments or teams to speed up communication and decision making processes internally
Production Adjustment	Modifying production schedules, configurations, or processes to adapt to supply chain disruptions
Digital Component Catalogue	Centralized digital system to track and manage component data and availability
Depopulation	Reducing the number of components in products to maintain production despite shortages
Prioritizing Critical Components	Focusing on the procurement and allocation of the most essential parts needed to keep production line running
Shortage Follow-up Meetings with Tier 1 Suppliers	Conducting regular meetings to discuss and manage the availability and supply of critical components with tier 1 suppliers
Regular Meetings with Tier 1 Suppliers	Establishing ongoing meetings, post-crisis, to maintain communication and manage supply chain risks with tier 1 suppliers
Shortage Follow-up Meetings with Semiconductor Suppliers	Conducting regular meetings to discuss and manage the availability and supply of critical components with tier 2 suppliers
Regular Meetings with Semiconductor Suppliers	Establishing ongoing meetings, post-crisis, to maintain communication and manage supply chain risks with tier 2 suppliers
Disruption Reaction Process	Flexible and reactive approach to manage sudden supply chain disruptions in real time
Reactive Risk Management Process	A structured method developed post-crisis to systematically identify and mitigate supply chain disruptions
Longer Forecasting	Extending the forecasting period to provide suppliers with better demand projections and as a result enhance planning
BOM - Bill Of Material Requirements	Requiring detailed information about the components of products to track availability and risks more effectively
Strategic Buffer	Maintaining stock of critical components to ensure continuity of operations during disruptive events

Table 3, The measures

These measures present wide range of strategies, ranging from preventive planning to adaptive responses. All of these are aimed at learning from the impact of unforeseen events and challenges on the company's production and business activities. The measures implemented by the case company involve leveraging existing resources more efficiently and strategically during times of crisis, as well as developing new strategies to enhance resilience and adaptability.

One of the key measures employed by Company A was the establishment of a dedicated Taskforce for crisis management. This cross-functional team helped with faster decision making, allowing the company to implement responsive measures in response to supply chain disruptions further details regarding this measure and all of the measure below can be found in Appendix 1, as mentioned before. Additionally, sometime during the crises Company A adopted proactive approaches, for example by creating a centralized file with information needed to handle all the challenges regarding semiconductor, extending its forecasting period, and prioritizing critical components within its operations. By providing suppliers with extended forecasting periods and focusing on securing the supply of crucial components, the company aimed to enhance supplier awareness and preparedness for future disruptions.

Furthermore, Company A emphasized the importance of building strong relationships with its suppliers, particularly tier 1 suppliers and semiconductor manufacturers. In addition to these measures, the company implemented various technical solutions to enhance supply chain visibility and traceability.

4.2.2 Measures Categorization Representing Internal and External Dimensions

Table 3 categorizes the various actions Company A took to respond to the semiconductor shortage crisis. These measures are divided into two categories targeting different dimensions of the organization.

Internal Measures	External Measures
Taskforce	Digital Component Catalogue
Intensified Cross-functional Working	BOM Requirements
Management Involvement, Internal	Longer Forecasting
Flat Hierarchy	Shortage Follow-up Meetings with Semiconductor Suppliers
Dedicated Semiconductor Team	Regular Meetings with Semiconductor Suppliers
Disruption Reaction Process	Shortage Follow-up Meetings with Tier 1 Suppliers
Reactive Risk Management Process	Regular Meetings with Tier 1 Suppliers
Alternative components	
Broker Market Scouting	
Production Adjustments	
Depopulation	
Strategic Buffer	
Prioritizing Critical Components	

Table 4, Categorization of Measures

Internal measures consist of actions that the company took to improve its own operations without involving external parties such as suppliers. These measures focus on enhancing internal processes, resource management, and operational adaptability.
External measures are adopted to support the company by establishing solutions across the entire supply chain, considering different tiers of suppliers. Table 4 illustrates this distinction by segregating internal measures into one category and external measures into another. As shown in the table, most of the measures aimed at improving the organization's own operations fall under the internal category, while those involving collaboration with external parties are classified as external measures.
Chart 2 illustrates the timeline of these measures under the next headline, indicating when they were implemented and if it's still included or omitted. The chart is colour coordinated to match the categories in Table 4, highlights that initial, during and post crises measures were implemented for both of the categories.

4.2.3 Measures Timeline

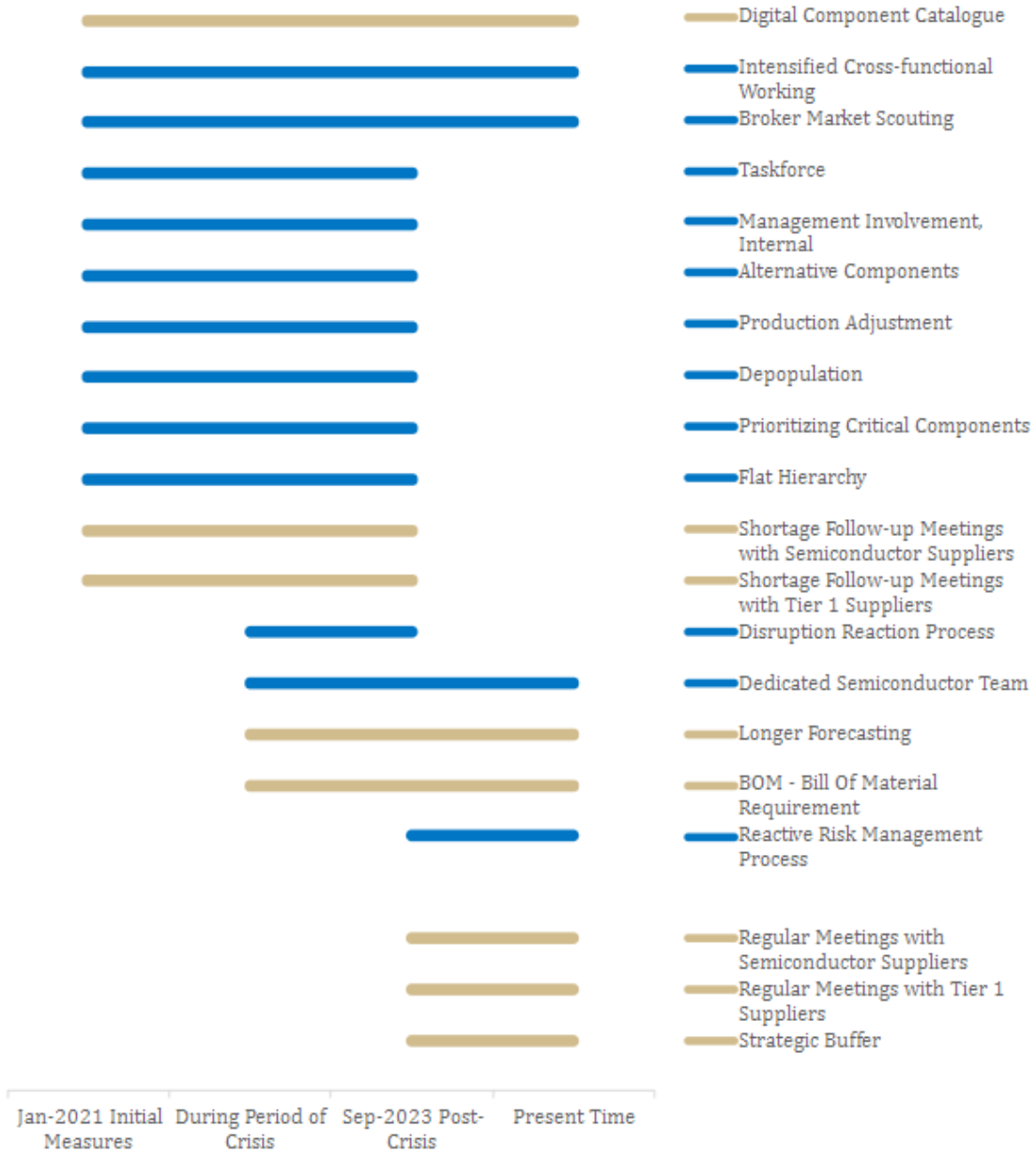

Chart 2, Timeline of the measures and colourised based on category of organisational dimensions

A visualisation of the measures in a timeline is presented above in Chart 2. The time period that is outlined bottom of the chart is initial measures, during period of crisis and post-crisis which refers to the initial period when the crisis started, end of 2020. Further, during the period of the crisis, referring to the time between 2021 until the end the crisis September 2023. Post-crisis is the period after September 2023. The last section named present time is a confirmation if the measure is still included in the todays process or not.

Initial Measures

When the semiconductor crisis started, Company A implemented several initial measures to mitigate the early consequences of the crisis. As mentioned before one of the first measures was the establishment of a Taskforce which one of the shortage managers pointed out;

''A Taskforce team was created to fully focus on events that caused disruption within the supply chain of any kind and effected the production. The Taskforce had also a close relationship with the bigger company that Company A is a part of to stress the bigger issues.''

- *(A1, Shortage Manager, personal communication, 2024)*

Company A had to also use alternative components to maintain production continuity. These alternative components played a crucial role in allowing the company to continue its operations despite the ongoing crisis.

''During covid and shortage of crucial components, technical changes was necessary. for example, using replacement component to get the production going.''

- *(A1, Shortage Manager, personal communication, 2024)*

Depopulation also played a significant role during the crisis, Company A could use fewer semiconductor in components for its vehicles to maintain production continuity due to this action and was crucial as an initial measure due to the impact. Initially, prioritizing products became crucial, and knowing which products to source in the broker market was important to ensure the acquisition of components that are essential for production. To help with prioritizing its component base, Company A initially used a digital component catalogue, providing a better understanding of the components and their importance to the production process. Company A had to also take further actions, including production adjustments, to continue operations.
Supporting all of these implemented initial measures were the establishment of cross-functional working teams, management involvement in operations further down the hierarchy, and a flatter hierarchy. Cross-functional teams included members from various departments working together to achieve synergies and effectively address the crisis. Management involvement was critical in decision making and resource allocation, ensuring that the measures were effectively implemented. The measure including the flatter hierarchy was implemented due to the environment that Company A was experiencing and the need for faster decision making. Pointed out from one of the risk managers, the cross-functional working environment was something got more intensified after creation of the Taskforce team.

''Collaborative problem-solving efforts, indicating the effectiveness of assembling cross-functional teams to tackle complex issues.''

- *(A8, Supply Chain Risk Manager, personal communication, 2024)*

In addition to the initial measures previously mentioned, Company A arranged Shortage Follow-up Meetings with both Semiconductor Suppliers and Tier 1 Suppliers. These meetings were crucial in improving the visibility of the supply chain, while offering crucial information about the availability status of critical components.
These initial measures were vital in stabilizing Company A's operations during the early stages of the semiconductor shortage crisis, they allowed the company to strategically prioritize and adjust its approach to continue production and mitigate or manage the impact of the disruption.

Measures During the Crisis

During the crisis Company A started to require Bills of Materials (BOM) from their suppliers. This step ensured that Company A was fully aware of the components included in the products they were acquiring, which was critical after the initial impact of the crisis. Knowing the exact components allowed Company A to better navigate the supply chain challenges and make better decisions about sourcing and

production. Having this information being so crucial Company A developed the process to easier access this information, Purchaser mentions;

> *''The semiconductor management software is an online tool, the company upload their components and the suppliers fill the BOM so the supply chain can be more visible and easier work with risk mitigation and be more proactive.''*
>
> - *(AX2, Purchaser, personal communication, 2024)*

To further manage the disruptive events after the initial impact, Company A implemented longer forecasting time frames. By extending their forecasting horizon, Company A aimed to anticipate potential shortages and plan accordingly, thus reducing the impact of disruptions.
Furthermore, Company A set up a Disruption Reaction Process, which was a reactive and flexible process for handling shortages due to the semiconductor crisis. This process as explained in Appendix 1 allowed the company to rapidly respond to the emergence of a new, unpredicted disruption by adapting strategies in real-time to ensure uninterrupted production.
Company A also set up a Dedicated Semiconductor Team to take care of relations and information exchange with tier 2 suppliers. This team was responsible for the digital component catalogue, providing insight into the components that are of risk during disruptive events. Now, the dedicated semiconductor team wasn't responsible for the previous versions of the digital component catalogue, once it became a software for specific components the team adopted that process and became responsible for it.
Aside from the disruption reaction process, all measures implemented during the crisis were based on information acquired during the crisis itself. The disruptive events prompted Company A to adopt these measures as a necessary response.

Measures Post-crisis
After the crisis, Company A acquired a lot of information to set up robust processes for future similar events. One of the measures adopted post-crisis was strategic buffering. This measure was implemented to ensure that Company A has enough components in stock to mitigate the impact of any future shortages.
To further enhance their supply chain resilience, Company A established Regular Meetings with both Tier 1 and Semiconductor Suppliers. These regular meetings developed closer cooperation and communication, which noticeably raised the visibility of the supply chain. Furthermore, Company A put into place a Reactive Risk Management Process. This strong post-crisis process was meant to offer a flexible and proactive position in mitigating unforeseen events that could influence the supply chain.

Measures Included in Today's Processes
Digital Component Catalogue
During the crisis, Company A realized the urgent need to have better visibility of the supply chain, especially of electronic components. Initially, the company used an established Part-number Database mainly utilized by the R&D department. That tool, while beneficial, was not designed to cater to the specific needs of the procurement department in monitoring and managing the necessary components during the crisis.
As the disruptions worsened, Company A made a huge step by developing a Centralized Database. This database, as explained in Appendix 1, was an extensive Excel file listing all the affected parts, which would help in giving visibility into the components affected by the crisis. While this Centralized Database improved the situation, it soon became clear that managing an ever-growing number of parts through an Excel file was inefficient and too complex. The volume and complexity of the data became far too much

for the Excel-based system, and it was painfully obvious that a more robust solution was needed.
In response to this challenge, Company A opted to use a more advanced tool after the crisis. They used a Semiconductor Management Software developed by another company in their group. This software provided a streamlined, structured approach in managing component visibility. Unlike the Excel file, this software was designed specifically to deal with the intricacies involved with semiconductor components and was therefore continued as a measure post crisis.

- Cross-functional Working

The crisis emphasized Company A's need for better cooperation between various departments in the Company in order to manage and mitigate the effects of semiconductor shortages as effectively as possible. Cross-functional Working was one major measure taken to address these failures. This involved the formation of special teams with the aim of promoting cross-functional cooperation between different departments within Company A.
These cross-functional teams were established to enhance the communication and harmonize decision processes better and as a result enabling an organized response to the crisis. These teams, which had members with diverse expertise from different departments, such as procurement, R&D, logistics, and production, could manage the multi-dimensional challenges posed by supply chain disruptions.

- Broker Market Scouting

During the semiconductor crisis, Company A had to adapt to the supply chain disruptions by finding other sources to acquire essential components for their vehicle manufacturing. One of the measures regarding this included the use of the broker market. At the start, this measure was implemented out of necessity to secure critical components which is explained in Appendix 1. The broker market offered them a flexible and immediate solution, where they could acquire components from alternative suppliers during extremely uncertain times. The flexibility it gave Company A is the main reason why they decided to keep this measure post crisis, but only using it on an ad hoc basis in the cases of new shortages. The shortage managers stress the importance this measure during the crisis which also reflects why it's still a crucial measure when a disaster accurse and creates a temporary shortage.

''One measure that helped us to save the production in the short term was the broker market. Broker market is where semiconductor manufacturer sells their old surplus good often through brokers. This was not a thing before the pandemic and it's too expensive to rely on, but highly effective during the crises.''

- *(A1, Shortage Manager, personal communication, 2024)*

- Dedicated Semiconductor Team

One of the most important measures was the creation of a Semiconductor Team that specifically addressed the challenges regarding semiconductors. This dedicated Semiconductor Team, involved in keeping constant communication with suppliers, was crucial when information sharing, and quick responses were required. The proactive communications approach allowed for better coordination with suppliers on ways of mitigating the shortage effect to maintain a steady flow of components during and after the crisis.
In addition, the team was responsible for updating the information in Semiconductor Management Software and ensuring that all the information therein was present and accurate. Moreover, detailed information regarding the can be found in the Appendix 1.

- Longer Forecasting

The semiconductor crisis revealed to Company A the need for a longer forecasting period to better manage the supply of the critical components. This measure had been established to provide suppliers with a more comprehensive forecasting report, enabling them to anticipate demand and obtain the necessary components well in advance.
The implementation of the longer forecasting period was a useful move aimed at mitigating these shortcomings and is also the reason for why it was continued post crisis. Company A could provide suppliers with the details of the needs of critical components over a much longer period as explained in Appendix 1.

''One initial measure was Company A's 12 month forecast but some of them have longer production cycle. This led to extending the forecast and implementing a 24 month forecast method to make sure the suppliers are aware of Company A's needs for the future.''
- *(A1, Shortage Manager, personal communication, 2024)*

- Bill of Material

For better supply chain visibility Company A required its semiconductor suppliers to provide a detailed Bill of Material (BOM) for products they procured from them. With information that they received on the components, Company A could get a better view of the supply status and adjust quicker to possible shortages or disturbances. This measure proved to be so useful that it was extended post crisis as it added the required visibility that was necessary.

- Reactive Risk Management Process

During the semiconductor crisis, Company A realized the need for a Reactive Risk Management Process in order to effectively cope with the dynamic environment and potential supply chain disruptions. The dedicated semiconductor team was instrumental in starting this approach through creating structured and robust processes to handle unforeseen disruptions. This was an important shift in the company's initial highly flexible approach that was started in the beginning of the crisis.
The team formulated a detailed and systematic approach that included a number of critical elements. One of the key components of this approach was the digital component catalogue. In addition to the utilization of the digital component catalogue, the Reactive Risk Management Process provided for proactive communication with Tier 1 and Tier 2 suppliers. The process included communication with these suppliers to ensure a smooth flow of information regarding the status of critical components. This includes reaching out to suppliers if a component is not listed in the digital component catalogue to ensure that no aspect of the supply chain is left out.

- Regular Meetings with Semiconductor Suppliers & Regular Meetings with Tier 1 Suppliers

In the course of the semiconductor crisis, it was realized by Company A that communication and visibility in their supply chain were weak areas that needed attention. Before that, Company A had maintained contact with their Tier 1 suppliers, who directly provided them with products. But as the crisis started, it became obvious that there was a need for much more intensive and direct communication with both the Tier 1 and semiconductor suppliers to get through the crisis.
In order to address that need, Company A initiated the holding of regular meetings with their Tier 1 and Tier 2 suppliers. The frequent interactions allowed Company A to gain real-time insights into the status of critical components and proactively address any emerging issues.

- Strategic Buffers

During the semiconductor crisis, Company A experienced shortages which necessitated the need for more robust supply chain strategies. As a reaction to this, the company implemented strategic buffers post-crisis to enhance resilience. The buffers act as stocks of critical components, thus ensuring the continuity of operations during supply chain disturbances. Further, this action was fitted into the company's processes continuously so that no production halt might occur in the future.

We have had buffer stocks at Company A for certain important electronic products during the past year, mostly components containing semiconductors.
- (A2, Senior Purchaser, personal communication, 2024)

4.2.4 Flexibility and Robustness

The researchers of this study developed a framework, Figure 5, to illustrate the relationship between the timing of each measure and the organization's strategic goals, whether aimed at enhancing flexibility or robustness.
In this framework, it can be seen how Company A's strategic responses evolved over time in relation to the semiconductor crisis. Initially, focus was naturally on flexibility, with measures taken to rapidly adapt to the situation and maintain continuity. As the time passes, the focus transitioned to building robustness, integrating strategies that would ensure stability and resilience against future events causing disruptions. Further, it is seen that some measures adopted initially during the crisis which were of flexible nature developed to robust processes post-crisis as Figure 5 and Chart 2 illustrates. This was done in order to maintain some flexibility in the present operations due to the uncertainty of the industry with new disruption event occurring sporadically. Most of the measures that were adopted during the crisis were of robust nature due to the knowledge that the company had acquired from the initial impact of the crisis, this measure was adopted in order for the company to establish some stability during a period of time that brought uncertainties regarding supply of components.

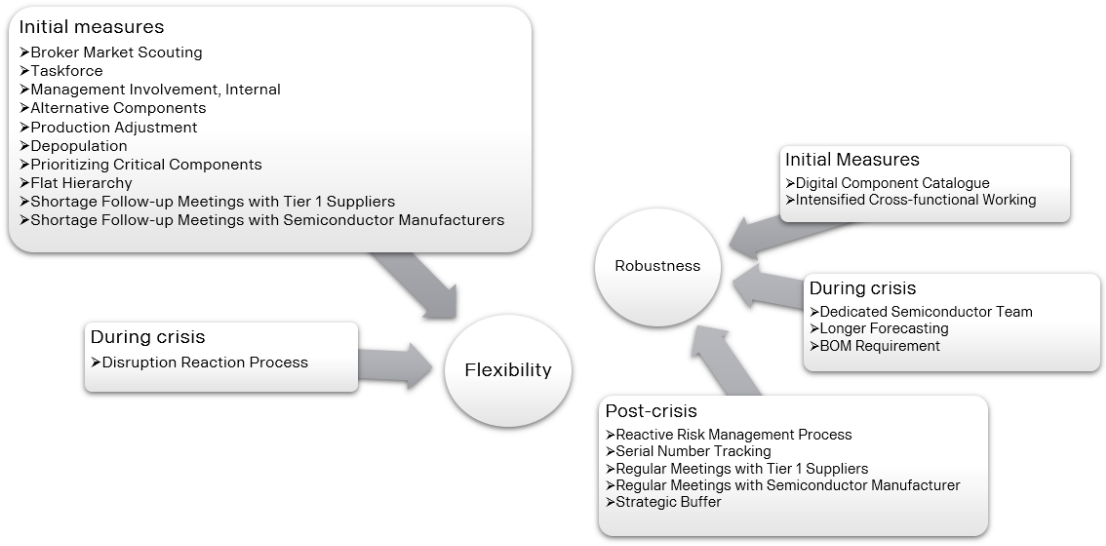

Figure 5, Flexibility and Robustness Framework

5. Discussion

In this section, the authors will discuss the empirical findings from Company A, starting with an explanation of the disruptions experienced in the semiconductor supply to provide context for the measures implemented to mitigate these impacts. The discussion will then explore the various measures implemented by Company A to mitigate the impacts of these disruptions. The alignment between the theoretical framework and empirical findings will also be discussed. This approach will provide a comprehensive view of how Company A navigated the crisis and enhanced its supply chain resilience.

5.1 Disruptions

The empirical findings from the research at Company A's procurement department focus on the disruptions in the supply chain starting in early 2020, escalating to a crisis due to a semiconductor shortage by late 2020. An analysis of these events, put into the context of the theoretical framework, shows how fragile the semiconductor supply chain is and the effectiveness of various strategies to mitigate the impacts (Ochonogor et al., 2023).

The pandemic restrictions due to COVID-19 in March 2020 started the first major disruption, leading to immediate shutdowns across different countries. This had a critical impact on the manufacturing sector, including the semiconductor industry, as demonstrated in the findings. Many companies lost profit during that time due to mandatory shutdowns. The supply and demand mismatch, driven by a significant spike in demand for electronic devices, did not have the highest impact on production as seen in chart 1, but it caused a huge shortage of components containing semiconductors. The theoretical framework explains that the semiconductor supply chain involves multiple stages and is complex, making it vulnerable to such demand fluctuations (Pereira et al., 2014; Durach et al., 2015).

The following disruptions, including the Texas winter storm, a fire at a semiconductor manufacturer in Japan, and COVID-19 outbreaks in Southeast Asia and China, compounded the existing semiconductor shortage. These events had a heightened impact due to the pre-existing supply and demand mismatch, although being common in the supply chain otherwise (Ochonogor et al., 2023).

Company A's ability to adapt quickly and implement effective responses highlights its resilience and strategic agility. The formation of the Taskforce was a major strategic response to reduce the effects of the semiconductor shortage. Actions like depopulation of components, sourcing from the broker market, and using alternative components were crucial in maintaining production continuity (Sheffi & Rice, 2005; Pereira et al., 2014).

5.2 Measures Categorization in Different Organisational Dimensions

By categorizing the case company's responses into two areas, internal and external, the effectiveness and strategic alignment of these measures through established theoretical frameworks can be discussed.

Company A's internal response to disruption, such as establishing a Taskforce and disruption reaction process, show an important reorganization to enhance agility and decision-making capacity (Sheffi & Rice, 2005). A flexible organizational structure is crucial for responding to disruptions effectively. By having a more flat hierarchy and involving management directly in crisis response, Company A increased its responsiveness and reduced the time required to implement critical decisions. These measures align with theoretical insights on the importance of building strong internal structures to adapt to sudden changes (Küffner et al., 2022). Further, Company A ensured that production was not affected and optimized resource use. Measures such as

sourcing from the broker market and using alternative components demonstrate an approach to resource management. These actions show the necessity of flexibility in resource allocation, allowing the company to adjust its production processes in response to available materials (Carbonara & Pellegrino, 2017; Tang, 2006). Moving on, visibility within the supply chain is critical for managing disruptions effectively. The theory highlights that visibility into the supply chain allows for better risk management and quicker responses to emerging issues (Durach et al., 2015; Brandon-Jones et al., 2014).

Lastly, regarding external measures, effective communication with suppliers was pivotal in managing the semiconductor shortage. Having follow-up meetings and then developing to regular meetings with semiconductor suppliers and Tier 1 suppliers are examples of the importance of maintaining open communication (Sheffi & Rice, 2005). The value of strong supplier relationships in managing disruptions is emphasized in the theory. By sharing information and coordinating with their suppliers, Company A could align their strategies and decrease the impact of the supply chain disruptions (Durach et al., 2015; Küffner et al., 2022). Additionally, the Digital Component Catalog further enhanced the visibility in the supply chain concerning the supplier's ability to provide components. By enhancing their information systems, Company A could predict possible bottlenecks and make more accurate decisions (Saqib et al., 2020).

5.3 The Categorization and Timeline Relation

The categorization in relation to the timeline, shows that measures from both categories were implemented throughout all phases of the crisis. This approach highlights that Company A had a thought through strategy to develop or adapt both dimensions within the organization. However, looking more into details of the timeline chart it reveals a pattern that it's worth to note. During the initial part of the crisis, a significant number of measures were focused on adaptation and resource management which were of internal nature according to the categorization. This observation is logical and aligns with theoretical findings, as it is crucial to be flexible and adaptable at the initial phase of a crisis (Pereira et al., 2014; Carbonara & Pellegrino, 2017; Küffner et al., 2022). The initial response to a disruption should emphasize flexibility to manage the immediate impacts and ensure continuity (Sheffi & Rice, 2005).

5.4 Company A's Response Measures to Crisis

The semiconductor crisis made the supply chain management of Company A go through different phases. Initially, the company was more flexible with measures of responsive nature to cope with immediate disruptions. Over time, these measures evolved into a more structured and robust process after the crisis, emphasizing the interconnectedness between flexibility and robustness (Ambulkar et al., 2015; Pereira et al., 2014; Küffner et al., 2022). This strategic shift ensured long-term resilience and stability, reflecting the necessity of integrating adaptive strategies to enhance the overall resilience of the supply chain (Durach et al., 2015).

5.4.1 Initial Measures

During the semiconductor crisis, Company A implemented several measures to manage and mitigate the initial consequences of the crisis. Initially, the company established a Taskforce and increased management involvement to ensure quick decision making and coordination, emphasizing the importance of flexibility in crisis management (Sheffi & Rice, 2005). These measures were crucial during the height of the crisis but were phased out as stability returned.

Due to the severe supply constraints Company A's procurement department faced, the company implemented further initial and flexible measures internally, such as production adjustments, depopulation and the use of alternative components. These

strategies allowed the company to maintain production continuity despite the disruptions due to their flexible nature (Pereira et al., 2014). However, once supply chains stabilized, this flexibility was no longer needed, leading to their discontinuation post-crisis.

To enhance supply chain visibility and resilience, Company A enhanced several of the external measures into permanent solutions. Shortage Follow-up Meetings with both Semiconductor and Tier 1 Suppliers were implemented into regular meetings, improving ongoing supply chain communication and risk management (Durach et al., 2015). This shift from flexible to robust processes highlights the interconnectedness of measures over time during a crisis (Küffner et al., 2022).

The digital component catalogue was developed into a more relevant system, enhancing the company's ability to manage and respond to disruptions efficiently. This evolution underscores the role of integrated systems in maintaining supply chain visibility and operational efficiency within the company (Somapa et al., 2018).

In summary, the initial measures implemented during the crisis were designed to be flexible to mitigate or manage disruptions as effectively as possible. While the effectiveness and suitability of these measures can be debated, the literature suggests that it is optimal to maintain flexibility initially during a crisis to quickly adapt to the changing environment.

5.4.2 During Measures

During the semiconductor crisis, Company A implemented several measures that evolved into robust processes post-crisis. Key measures included the formation of a Dedicated Semiconductor Team and the adoption of a Bill of Material (BOM) requirement. The Dedicated Semiconductor Team managed supplier relationships and updated digital component software, ensuring continuity and enhancing resilience (Pereira et al., 2014). The BOM requirement enabled detailed tracking of component availability and risks, strengthening supply chain management and providing crucial visibility (Brandon-Jones et al., 2014). These measures, initially developed during the crisis, became robust processes post-crisis.

Additionally, Company A introduced longer forecasting periods to provide suppliers with comprehensive demand projections, allowing for better planning and resource allocation. This measure proved so effective that it was included in the standard operations post-crisis, further enhancing supply chain robustness (Klibi et al., 2010). Further, the disruption reaction process, a flexible measure to quickly address sudden supply chain issues allowed Company A to receive real time adaptation, ensuring continuous production despite the unpredictable environment, but was discontinued post-crisis as stability returned (Tang & Tomlin, 2009).

Once the company was in a crisis, they had to establish new measures as they became more aware of the necessary actions to better manage their environment. The measures that Company A implemented align with the theory of building a strong foundation to transition from a more flexible setting to robust processes. This is clearly seen in the timeline, majority of the measure that were implemented in during the crisis were implemented as robust processes post-crisis.

5.4.3 Post-crisis Measures

Company A implemented several robust measures post-crisis to ensure supply chain resilience. The Reactive Risk Management Process, developed by the dedicated semiconductor team, involves a structured approach to identifying and mitigating risks, effectively transforming the initial flexible measure into a structured and robust system (Ambulkar et al., 2015).

To maintain strong supplier relationships and continuous communication, Company A started holding regular meetings with both semiconductor and Tier 1 suppliers post-

crisis. These meetings provide updates on component availability and potential disruptions, fostering collaboration and transparency, thereby strengthening supply chain robustness. This measure was updated from the initial communication measures that were implemented during the crisis (Küffner et al., 2022).
Additionally, Company A implemented strategic buffers, maintaining stock of critical components to mitigate future supply chain disruptions. This measure ensures that operations can continue during disturbances, making the supply chain more robust and resilient to unexpected disruptions (Christopher & Peck, 2004).
In summary, Company A implemented several measures post-crisis. The majority of these measures, as seen in the measure timeline, were established during the crisis or at its onset. This approach aligns closely with the theory, which emphasizes the interconnectedness of measures implemented over time.

5.4.4 Flexibility and Robustness

Company A's strategic response to the semiconductor crisis highlights a critical shift from initial flexibility measures to more robust processes after the crisis. This transition aligns with theoretical frameworks that emphasize the need for flexibility as an immediate reaction to disruptions and robustness for long-term stability (Pereira et al., 2014; Sheffi & Rice, 2005).
Initially, Company A focused on high flexibility in its approach. The measures adopted during this stage emphasized rapid adaptability to the volatile and uncertain crisis environment (Pereira et al., 2014). The company established teams and processes that allowed for quick decision making and dynamic responses to emerging challenges. This flexible approach was essential in managing the immediate impacts of the crisis and ensuring continued operations despite significant supply chain disruptions (Carbonara & Pellegrino, 2017).
During the crisis, the focus shifted toward more structured approach, while still maintaining a degree of flexibility. This intermediate phase involved the development of processes that could respond in an organized manner to ongoing disruptions, balancing adaptability with the need for more structured responses (Sheffi & Rice, 2005). For example, Company A introduced longer forecasting periods to provide suppliers with comprehensive demand projections, which allowed for better planning and resource allocation (Christopher & Peck, 2004; Tang, 2006). This approach was crucial for managing disruptions effectively and maintaining supply chain continuity.
After the crisis, Company A's strategy shifted to robustness. The measures implemented in this stage aimed to ensure long-term stability and resilience against future disruptions (Ambulkar et al., 2015). By introducing more robust processes, such as improved risk management and enhanced visibility throughout the supply chain, the company aimed to build a more resilient supply chain (Durach et al., 2015). These robust measures provided a systematic framework for handling risks and maintaining operational continuity, reflecting a strategic shift from the initial flexibility required during the crisis (Küffner et al., 2022).
The transition from flexibility to robustness underscores the interconnectedness of supply chain strategies over time (Küffner et al., 2022). It demonstrates how initial adaptive measures can mature into stable, long-term processes that strengthen the company's supply chain. This approach ensures that immediate challenges are addressed and that the organization is prepared for future disruptions, maintaining sustained effectiveness and competitiveness in its operations (Sheffi & Rice, 2005).
In summary, this strategic development of measures implemented highlights the importance of adaptive supply chain management during a crisis. Company A's journey from initial flexibility to robustness not only exemplifies effective crisis management but also aligns with key theoretical frameworks, highlighting the necessity of a dual approach to disruption management over time. By integrating rapid adaptability with

long-term resilience, Company A has positioned itself to not only survive immediate crises but to thrive during uncertain events. This comprehensive strategy ensures sustained operational effectiveness and reinforces the company's competitive edge in an increasingly volatile global market. Thus, the case of Company A serves as a compelling blueprint for other organizations aiming to enhance their supply chain resilience and overall strategic agility. (Pereira et al., 2014; Sheffi & Rice, 2005; Küffner et al., 2022).

6. Conclusion

The research was based on a deep understanding of the complex nature of the semiconductor supply chain. Rapid technological advancement has made semiconductors a crucial component in modern electronics, but this has simultaneously made their supply chains more vulnerable to disruption. The COVID-19 outbreak brought the vulnerabilities of global semiconductor shortages into light. Company A, being an automotive company heavily dependent on semiconductors, faced huge operational challenges due to these disruptions. Resilient strategies became necessary to make supply networks less vulnerable to disruptions. This scenario put pressure on automotive Original Equipment Manufacturers to develop and retain a competitive advantage.

Based on this background, the purpose was to enhance understanding of the automotive supply chain's responses to semiconductor shortages by systematically assessing and analysing the measures adopted or excluded during different phases of the crises. Following this purpose, the authors gathered data through interviews mainly, but also literature review and secondary data, about the period between the start of the crises until today. The primary focus of the study was on measures adopted, but analysing the most impactful disruptions that caused the crisis helped put the situation in perspective.

In conclusion of analysing the disruptions, six disruptions were brought to attention. First being the COVID-19 outbreak in Europe which was the leading cause of the second disruption, the supply and demand mismatch. After the second disruption which marks the start of the crises, the following events had a larger impact than they should have had. Lastly, as soon as the effect of the supply and demand mismatch was no longer a factor, that marked the end of the crisis.

6.1 Research Question 1: What measures were adopted by Company A in response to semiconductor shortages?

Regarding the first research question, the measures adopted by Company A are visualized in Table 4, and the definition of each measure is described in the empirical findings. Dividing the measures into two categories, internal and external, demonstrated that actions were taken towards all aspects of the organization to mitigate the crisis.

The assembly of a Taskforce team, being the most influential measure, showed that Company A adapted its internal structure and processes to face the crisis. The internal measures helped the company improve decision-making by enabling more knowledgeable and quicker decisions. Additionally, measures focusing on internal operations included resource and component allocation to secure production continuity.

External measures focused on enhancing collaboration and communication with external parties, such as suppliers, to manage supply chain disruptions effectively and securing supply. Improving visibility and information sharing with external partners ensured alignment and stronger relationships within the supply chain, which is crucial in the semiconductor market where the number of suppliers is limited.

The categorization in relation to the timeline of the measures in Chart 2 shows that measures were implemented throughout all phases of the crisis, targeting both internal and external aspects of the organization. This emphasizes that Company A gradually improved in all areas to effectively face the crisis in an efficient way according to the literature.

6.2 Research Question 2: Which measures are omitted or included in today's processes?

As for the second research question, the measures can be visualized in a timeline on chart 2. After analysis of the timeline, the authors conclude that most of the initial measures adopted were measures of immediate responsive nature that were omitted later on towards the end of the crises. The digital component catalogue was an initial measure that is still in today's processes. These measures were developed during different phases. The process from immediate responses to proactive solution to secure the supply chain visibility for future disruptions that may occur, this also applies to the follow-up meetings with Tier 1 suppliers and manufacturers which developed into regular meetings. The measures adopted during the crisis were more proactive and most of them are still included in today's processes besides the disruption reaction process which developed into a reactive risk management process that is included in today's processes. Lastly, some measures were adopted post-crisis but all of those are still included in today's processes. Most of those measures are developments of actions taken initially or during the crises, like strategic buffering for securing production continuity.

6.3 Research Question 3: Why did certain measures get included or omitted?

Concerning the third research question, the semiconductor supply chain is highly vulnerable to disruptions with consequences that reach far within the supply chain. The theoretical framework provides a comprehensive understanding of the supply chain's complexity and the strategic measures required to navigate disruptions. The analysis suggests that continuous innovation, strategic management, and proactive measures are crucial for maintaining supply chain resilience and ensuring the stability of production processes.

Omitted measures were mostly initial flexible measures. Moving forward and stepping out of the crisis, the company mitigated these processes to build a more robust organization. Many of these measures were implemented due to necessity regarding mitigating the initial impact of the semiconductor shortages. These measures wouldn't provide any substantial effects if they weren't implemented in a crisis situation. For example, depopulation, which is extensively explained, wouldn't have made any positive impact on Company A if it was implemented today since there isn't an ongoing crisis. Therefore, a lot of these measures were implemented due to a specific event and then omitted due to the event passing. That is also why most of the measures that were implemented, which are of internal nature, are omitted since they only bring an initial flexibility that the company urgently needs to combat a disruption.

The updated measures are a great example of how the initial actions were to adapt to the situation and be more flexible but by realizing the importance of those measures Company A updated each measure to more robust processes. From a more responsive approach to a more anticipatory process that helps the organization foresee challenges or have faster solutions to sudden disruptions.

Most of the measures that are still included in today's processes are updated measures that were initially adaptive actions during the crises. Through best practices, the organization learned how different measures impacted the processes. Updating the measures helps the organization to easier apply them to its processes because they've already been introduced, tested, and proven efficient. This is emphasized in the case due to measures that were included in present operations being connected to visibility and information sharing which brings a more robust setting to the current processes. An example regarding this is seen in the measure digital component catalogue. This measure was updated during the crisis as mentioned in the empirical findings. Post-crisis this measure became a robust solution to the issues that the company had regarding shortages.

With including all the measure towards robustness in today's processes and developing measures towards flexibility to more robust processes and make them standardised, it has been seen that flexibility also needed. For example, the broker market sourcing is a measure that is still included in today's processes and it is ready to be used if needed. This measure help Company A in critical moments when critical components are needed. Company A still include this measure to ensure some flexibility in times needed.

6.4 Suggestion for further research

One aspect the authors wanted to include in this research was an external perspective. how suppliers reacted to the measures implemented by Company A during the crisis? Due to time constraints, this aspect was not investigated. However, for future studies, including this perspective would add depth to the analysis of the implemented measures. By considering external actors, such as tier 1 and tier 2 suppliers, researchers can better assess the effectiveness of these measures in managing the crisis. Given the interconnected nature of the industry, where actions by one actor can significantly impact others, this question becomes increasingly important.

Furthermore, since Company A is part of a larger group within the automotive industry, it would be useful to examine how other companies within the group reacted to the semiconductor crisis. Were the measures they adopted similar to those of Company A, or did they take different approaches that were perhaps more effective or less? By considering the actions of other companies, a more comprehensive framework can be established to guide how companies should respond during times of uncertainty and shortages.

6.5 Limitations

One of the primary limitations of our study was the reliance on interviews as the main source of data collection. Initially, the study was supposed to be fully based on interviews with employees who had experienced the semiconductor crisis. However, due to the specific details required, many employees struggled to recall information from events that occurred a few years ago. This memory lapse necessitated the inclusion of quantitative data to supplement the interviews and ensure a more comprehensive understanding of the situation.

Additionally, a significant limitation arose from the time constraint. Our study aimed to include perspectives from tier 1 and tier 2 suppliers to assess how the measures implemented by Company A during the crisis affected these external actors. Unfortunately, due to the lack of time, it forced the authors to remove the research question related to their reactions and the impact of the measures on them. This exclusion limited the ability to fully explore the interconnectedness of the supply chain and the broader effectiveness of the crisis management strategies.

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Appendix

Appendix 1 – Definition of Each Measure

Taskforce

A dedicated team called the Taskforce got assembled for crisis management in the biggening of 2021. The semiconductor shortage crisis posed significant challenges for Company A, leading to disruptions in its supply chain and production operations. In response to the crisis, the company established a dedicated team to implement measures aimed at stabilizing the situation and ensuring continuity of operations within the company. Initially facing a critical crisis, the company's immediate focus was on addressing the urgent supply chain challenges through a series of reactive measures. As one of the interviewee mentioned;

''Early on during the crises the Taskforce were created which I was a part of. having the expertise and the insights from others in the Taskforce, we could evaluate and decrease the impact of the disruption in different departments, especially focusing on the more crucial once.''

- *(A2, Senior Purchaser, personal communication, 2024)*

The reactive measures implemented by Company A were diverse and comprehensive, reflecting the nature of the challenges at hand. The company established a cross-functional virtual and agile team to facilitate rapid decision-making and coordination. This team took part in scouting and sourcing of broker parts, conducted 3-party calls with key suppliers such Tier1 and actors farther in the supply chain, and made production adjustments to take into account standard changes and improvements. Recourses managements such as depopulation and using alternative components, which will be explained later in this section, were also implemented to address component shortages. Additionally, strategic buffering of critical parts at Company A, top management meetings with Tier1 and Tier2 suppliers and coordination were integral measures of crisis management approach. Furthermore, the company developed a 12-24 month forecast for components containing electronic parts, enabling better anticipation of future supply chain challenges.

The reactive crisis management measures proved effective in stabilizing the situation and significantly improved Company A's supply chain resilience. By the first quarter of 2022, Company A reported no shortages, marking a turning point in the crisis. With the situation now stable, company A ended the Taskforce and transitioned crisis management regarding semiconductors responsibilities to a dedicated semiconductor team.

Dedicated Semiconductor Team

After the semiconductor shortage crisis was over and an intensive measure such as the Taskforce wasn't needed, Company A recognized the need for a specialized team to proactively manage and mitigate future supply chain challenges related to semiconductors. As a result, the Dedicated Semiconductor Team was established as a key measure taken post-crisis. This team, a proactive initiative, plays a critical role in ensuring the company's resilience against similar disruptions in the future.

The Dedicated Semiconductor Team's purpose was to maintain direct contact with semiconductor manufacturers, thereby ensuring a robust and reliable supply of critical components. By having close relationships with manufacturers, the team can gain insights into potential supply chain issues early and work collaboratively to develop solutions before these issues escalate into crises.

One of the core responsibilities of the Dedicated Semiconductor Team is to build upon the measures and lessons learned during the crisis. The team continually evaluates the strategies that were effective in mitigating the impact of the previous disruptions. This includes enhancing the digital components catalogue, optimizing the use of alternative components and developing Disruption Reaction Process to Reactive Risk Management Process for more robust and thought through action, these measures are explained later in the report. The team is also focused on developing new proactive measures. This involves staying ahead of industry trends and adopting innovative technologies to improve supply chain visibility and responsiveness.
Furthermore, the team emphasizes relationship management, not just with semiconductor manufacturers but also with Tier 1 suppliers. By maintaining strong, collaborative relationships across the supply chain, the Dedicated Semiconductor Team can manage better coordination and quicker responses to future challenges.

Alternative Components
Another measure implemented by Company A was the utilization of alternative components during the crises. This approach involved leveraging alternative components to ensure continuous production, even during the component shortages. Sometimes where specific components weren't available, Company A turn to using alternative components that could replace or function temporarily, enabling the continued assembly and delivery of trucks without halting the production entirely. This adaptive strategy allowed Company A to maintain production levels and meet customer demand despite supply chain disruptions. As one of the managers highlighted in an interview;

''While some suppliers were hesitant to engage directly with manufacturers, others actively provided alternative suggestions for components.''
- *(A5, Supplier Shortage Manager , personal communication, 2024)*

This collaborative effort between Company A and its suppliers exemplifies the importance of proactive communication and overcoming supply chain disruptions and ensuring business continuity.

Broker Market Scouting
Exploring the broker market as a last source reactive measure was also a crucial approach at the time. Another measure undertaken by Company A was the exploration of the broker market as a last-resort. In response to critical semiconductor component shortages, Company A's procurement team proceeded into the broker market to source the components needed for production. This approach served as an emergency plan to secure essential parts when conventional supply channels were unable to meet demand. However, this reactive measure came with significant drawbacks, notably the high prices of components in the broker market. However, despite the higher costs, Company A deemed it necessary to procure these components to ensure the continuation of operations otherwise the cost of production stop would've been far greater. This adaptive approach highlights Company A's commitment to maintaining production and meeting customer demand, even in the face of supply chain disruptions. While exploring the broker market provided a temporary solution to component shortages, it underscored the importance of strategic planning and risk mitigation strategies to minimize the impact of disruptions on business operations.

''One measure that helped us to save the production in the short term was the broker market. Broker market is where semiconductor manufacturer sells their old surplus good often through brokers. This was not a thing before the pandemic and it's too expensive to rely on, but highly effective during the crises.''

- *(A1, Shortage Manager, personal communication, 2024)*

Management Involvement

Company A implemented another vital measure including the involvement of top-level management in internal meetings. Recognizing the severity of the disruptions during the crisis and the need for swift and effective decision-making, Company A's top executives participated in meetings that they typically wouldn't attend. This approach was established to enhance cross-functional communication and foster a deeper understanding of the challenges at hand among all levels of the organization. By involving higher-ranking employees in discussions related to supply chain disruptions, they thought to leverage their expertise and strategic insights to develop effective solutions and mitigate the consequences of disruptions. This was mentioned by several interviewees, as one of the Procurement Advisor's at the company stated;

''Daily meetings with top management were effective in making quick decisions to address crises.''

- *(A6, Procurement Advisor, personal communication, 2024)*

As a take away from the interviews the group understood that this collaborative approach not only ensured better coordination across departments but also facilitated that decision making processes were well though through and responsive to the situation. Ultimately, the involvement of top-level management in internal meetings underscored Company A's commitment to addressing supply chain disruptions effectively and decisively.

Flat Hierarchy

Company A also established a flatter hierarchy to enable more agile decision making. Recognizing the urgency of responding to supply chain disruptions faster, Company A restructured its organizational hierarchy to empower employees at buyer levels to make decisions by their own judgement. By decentralizing decision making, Company A aimed to minimize the time it takes for decisions to be made, thereby enabling faster responses during the crisis.

This was a crucial measure during the crises sense when an event accrued that would possibly lead to disruption within the supply chain, meaning leading to a shortage, that would be the case for all the automotive manufacturer. So, the company with the fastest decision-making process would get the few components that where still available. This usually was in the broker market.

'' This thing with broker buys, it was like it could be taken at a very flat level so to speak, the sums that were bought there, normally go through some approvals from the managers. Just that thing with broker buys, you almost had to decide in a few hours whether to buy or not buy and then you couldn't have long escalation chains, then it was like you got the mandate to make the decisions yourself or at the group manager level. Usually, it worked well and we saved many deals on that.''

- *(A2, Senior Purchaser, personal communication, 2024)*

This proactive approach allowed employees closer to the operational frontline to take critical decisions, leveraging their expertise and insights to address challenges effectively. Moreover, flattening the hierarchy promoted a culture of empowerment and innovation within the organization, fostering a more agile and responsive workforce.

Intensified Cross-functional Working

One significant measure implemented that was talked about a lot in the interviews was the adoption of collaboration within the different departments of the company, both

during and after the crisis, fostering cross-functional cooperation. This is what several Purchaser had to say about cross-functional working;

''It has been interesting as mentioned, this thing with the crisis, it has been tough but very developmental I think for our company to find new ways but also the organization has always been flexible and adapted quickly and found solutions. The Taskforce that was created, where we worked together cross-functionally and very good contact with R&D also where you can discuss solutions.''

- *(A3, Senior Purchaser, personal communication, 2024)*

Recognizing the complexity of supply chain challenges and the need for efforts to address them effectively, Company A emphasized collaboration across departments and functions within the organization. This collaborative approach involved breaking down silos and promoting open communication among different teams, including procurement, logistics and R&D for instance. By focusing on cross-functional collaboration, Company A aimed to leverage the diverse expertise and perspectives of its workforce to develop comprehensive and innovative solutions to supply chain disruptions. Moreover, this collaborative approach extended beyond internal departments to include external stakeholders such as suppliers for collaboration and mutual support. During and post-crisis, the company strived for a collaboration across different teams, recognizing that collective efforts and shared responsibility are essential for building resilience and driving growth. This was a segment that the case company really developed and according to the Risk Managers it was a crucial change for a more proactive approach;

''Seeing the difference before and after crises is very promising, collaborative problem-solving efforts, indicating the effectiveness of assembling cross-functional teams to tackle complex issues.''

- *(A8, Supply Chain Risk Manager, personal communication, 2024)*

Production Adjustment

Another measure adopted by Company A was production adjustment to changing conditions. This approach involved adapting manufacturing processes in response to the circumstances, such as component shortages or market demands. This could include adjusting the production line of a product or just adjusting the schedule of the production. By adjusting production strategies, Company A aimed to optimize resource allocation, minimize disruptions and maintain their operational efficiency. This measure enabled Company A to remain agile and responsive to dynamic conditions, ensuring the continued delivery of products to customers while navigating challenges caused by disruptions.

Digital Component Catalogue

Having a centralized file/software with all the information needed found out to be crucial as a first step to face different disruptions. A digital component catalogue is any integrated approach adopted or developed by Company A during the semiconductor shortage crisis to have all the information needed in the same place. This catalogue evolved through three distinct phases. Initially, the Part-number Database, primarily used by the R&D department, was repurposed to identify electronic components. This was followed by the creation of a Centralized Database, which allowed for a more systematic and cross-functional approach to get more up to date information about components used in the production that contained semiconductors. Finally, the adoption of the Semiconductor Management Software provided an advanced, integrated platform for real-time supply chain visibility, risk mitigation, and proactive decision-making. Each stage in the development of having a digital component catalogue

contributed to improving Company A's resilience and operational efficiency during and after the crisis. Each approach is described more thoroughly below.

- Part-number Database

Company A's R&D department already used a tool, that in this report it's called the part-number database, to manage all components used in its final product. Although primarily intended for the R&D department, the Taskforce leveraged this tool in the very beginning of the crises to compile a comprehensive list of electronic components. Despite not being designed for this specific use, the tool helped to identify up to 90% of components potentially containing electronic devices. Subsequently, these components underwent further analysis to determine if they contained semiconductors, their type and production origin. This enabled the Taskforce to identify potential disruptions based on affected factories, identifying critical electrical components for targeted mitigation efforts. While the part-number database served as an initial measure to gain insight into the crisis's scope, a centralized database was later developed to provide more accurate information for ongoing management which is explained in the next section.

- Centralized Database

During the crisis, Company A utilized a centralized database, an Excel file, as a measure to manage components affected by disruptions. This centralized database served as a centralized archive for all the components to easier point out the critical components and gather information faster as one of the Shortage Managers describes;
Before the semiconductor management software which will be explained in the next points, the centralized database provided visibility into components that was effected by disruptions, enabling the company to handle any components that are of risk. This approach helped the company to become more cross-functional and centralized, according to a Supplier Escalation Manager;

''The centralized database is still in use, which was something that existed before the crisis but was further developed during the crisis. I remember there was a lot of focus on centralizing all information and working more cross-functionally.''

- *(A4, Supplier Escalation Manager, personal communication, 2024)*

By maintaining this centralized database, Company A could quickly identify and prioritize components experiencing supply chain disruptions, allowing for timely decision making and allocation of resources to mitigate the impact of disruptions. Although the centralized database served as an useful interim solution during the crisis, the subsequent adoption of semiconductor management software further enhanced Company A's supply chain visibility and resilience by providing a more comprehensive and integrated platform. As one of the Purchaser informed us the centralized database had its own difficulties.

''During the crises a centralized database was developed which all the components that were used at our company was included but hard to know which component contained semiconductor and if so where the semiconductor was sourced from. This made it very hard to generate measures for a specific product if a shortage would accrue.''

- *(AX2, Purchaser, personal communication, 2024)*

- Semiconductor Management Software

A software for supply chain visibility enhancement post-crises was introduced. By leveraging the database on the software for various components, including raw materials, the case company was able to enhance visibility and traceability across its entire supply chain. According to one of the Purchasers, who also where part of the

Taskforce and worked with strategic semiconductor management, mentioned the importance if this software that helps other measures to develop; Z

''The semiconductor management software is an online tool, the company upload their components and the suppliers fill the BOM so the supply chain can be more visible and easier work with risk mitigation, and be more proactive.''

- *(AX2, Purchaser, personal communication, 2024)*

This enabled Company A to streamline legal compliance efforts by centralizing documentation and certifications for all components. Moreover, integrating quality assurance processes within the software allowed the case company to monitor and manage the quality of components throughout the supply chain, ensuring compliance with standards and regulations.
Additionally, the data in the software served as a tool for bottleneck management by identifying and addressing bottlenecks in the supply chain promptly. Change management processes were also integrated into the semiconductor management software, facilitating efficient communication of changes with suppliers.
Overall, using this tool for multiple components and functionalities for electronics enhances Company A's supply chain visibility, risk mitigation capabilities and proactive decision making. By centralizing component data and facilitating collaboration with suppliers, the software strengthens Company A's resilience towards disruptions and supports its strategic objectives in the supply chain.

Depopulation
In response to the crisis and component shortages, Company A adopted depopulation as a strategic measure to ensure the continued delivery of trucks to customers. By recognizing the challenges posed by limited component availability, Company A made the decision to streamline final product's components through depopulation. By reducing the number of components integrated into the final product, Company A aimed to mitigate the impact of shortages on the production processes. This approach allowed Company A to maintain its commitment to customers by ensuring the delivery of trucks despite the challenges posed by component shortages.

Prioritizing Critical Components
By implementing the requirement for a bill of material from tier 1 suppliers, the case company obtained the ability to prioritize critical components within their operations. This measure allowed Company A to identify and focus on components that are crucial for their production processes. By having visibility into the bill of materials provided by tier 1 suppliers, Company A could strategically prioritize the procurement of components that are deemed most critical to their operations. This prioritization ensured that resources and efforts were allocated correctly, focusing on securing the supply of crucial components to mitigate the risk of disruptions and maintain smooth operations. Ultimately, by prioritizing critical components in the bill of materials, Company A strengthened its resilience to supply chain disruptions and enhanced its ability to meet the demand

Shortage Follow-up Meetings with Tier 1 Suppliers
During the semiconductor shortage crisis, one of the initial measures implemented by Company A was to hold regular shortage follow-up meetings with their tier 1 suppliers. These meetings were critical for addressing immediate supply chain disruptions and ensuring continuity in production. By establishing consistent communication, Company A could be more informed but also inform the suppliers more about the needs from their side. Identifying and responding to emerging issues and prioritizing the allocation of limited resources was great help during the crises. These follow-up meetings not only

provided real-time insights into the supply chain status but also facilitated collaborative problem-solving, creating a partnership among Company A and its key suppliers.

Regular Meetings with Tier 1 Suppliers

A significant measure implemented after the crises by Company A was the continuing the relationships with tier 1 suppliers. Recognizing the role of tier 1 suppliers in the supply chain, Company A focused on building collaborative and strategic partnerships with these key actors in the supply chain. This relationship was already a part of the processes before the crises but going through the crises and having rapid shortage follow-up meetings changed the dynamic of the relationship between Company A and its suppliers. By strengthening relationships with tier 1 suppliers, Company A aimed to enhance communication, trust and mutual understanding. This proactive approach involved regular engagement with tier 1 suppliers, enabling Company A to gain deeper insights into supply chain dynamics and potential risks.

''We learned a lot from that period and having a closer relationship with different actors within the supply chain was one of them. Semiconductors are such unique products that it is not possible to use a procurement strategy or transformation strategy, we need close dialogue with suppliers and manufacturers and continuous adaptation to different events to find solution before the impact from a disruption.''

- *(A1, Shortage Manager, personal communication, 2024)*

Shortage Follow-up Meetings with Semiconductor Suppliers

Company A recognized the importance of having strong relationships with semiconductor suppliers during the semiconductor shortage crisis. Understanding that having the information and updates about semiconductor availability as soon as possible were crucial for developing effective mitigation measures. Disruptions at these lower tiers could have significant negative impacts on production which wasn't as big of an issue before the crises.

During the crisis, Company A reached out to semiconductor suppliers affected by shortages or other disruptive events. The company initiated follow-up meetings with these suppliers to receive timely updates and information. These meetings proved to be an effective reactive measure, helping Company A to be prioritized by suppliers and reduce the impact of disruptive events. Leveraging its connection with a larger organization that it's a part of, which had broader recognition and influence among suppliers, along with the efforts of the Taskforce, Company A successfully navigated the crisis.

Regular Meetings with Semiconductor Suppliers

Following the crisis, Company A continued the connection as a proactive approach by establishing regular meetings with semiconductor suppliers, a responsibility now managed by the dedicated semiconductor team. By extending relationship building efforts beyond the tier 1 suppliers, Company A aimed to gain greater visibility into the entire supply chain network and mitigate risks associated with potential disruptions at lower tiers. Reaching beyond the tier 1 suppliers can be risky and have consequences. But as these risks were discussed during the interviews, it got clear that doing it systematically and thought through can help the processes. Company A had great communication with the tier 1 suppliers and was very clear that their approach is for their both interests. One of the Supplier Escalation Managers mentioned;

''Certainly, we seek approval from tier 1 suppliers before taking action. If our company needs to address issues, such as contacting manufacturers with direct distribution, we obtain consent from them. It's important to ensure transparency and collaboration, so we explicitly state our intentions when reaching out, emphasizing that it's to assist them, not

to undermine their authority. This approach fosters a cooperative atmosphere, reinforcing our shared goal of maintaining production. However, reliance on external distributors poses risks, as does excessive intervention, which can lead tier 1 suppliers to become complacent."

- *(A4, Supplier Escalation Manager, personal communication, 2024)*

This approach enabled Company A to establish direct lines of communication with semiconductor manufacturer, on an early note identifying potential disruptive events for proactive solutions.

Disruption Reaction Process

During the crisis, Company A worked with a disruption reaction process to manage potential disruptions in the semiconductor supply chain. This reactive measure was carried out by the Taskforce and involved immediate actions such as contacting suppliers and manufacturers to gather information and updates before the impact of a disruption could be fully realized. By reaching out to key stakeholders, the Taskforce could assess the situation, understand the potential risks and plan necessary responses. This engagement was crucial in minimizing the impact of disruptions and ensuring the continuity of supply chain operations during the crisis. This process later on developed into a standardized process that is explained next.

Reactive Risk Management Process

The reactive risk management process is the standardized process of the disruption reaction process which is designed to address potential disruptions within the semiconductor supply chain as soon as an event occurs. This process begins with Company A contacting suppliers to request updates on the event's impact. The collected information helps determine the necessary course of action, which may involve addressing damages, delays or shortages. This proactive engagement allows Company A to quickly identify risks and implement measures to mitigate the impact. By maintaining close communication with suppliers, Company A ensures continuity in its supply chain operations and adapts to any emerging challenges.

Longer Forecasting

Another measure implemented by Company A was extending the forecasting period to enhance the supplier awareness. Recognizing the importance of being proactive and communicating in mitigating supply chain disruptions, Company A extended its forecasting period beyond the typical timeframe. For critical components, such as semiconductors, Company A implemented a 24-month forecast, providing suppliers with a longer-term outlook of the demand and supply. For other non-crucial components, Company A maintained a 12-month forecast. By providing suppliers with extended forecasting periods tailored to the criticality of components, Company A aimed to enhance supplier awareness and preparedness for future production needs due to the crisis that was experienced. This proactive approach established a closer collaboration between Company A and its suppliers, fostering a shared understanding of upcoming challenges and opportunities. Further, it allowed suppliers to adjust their production schedules and inventory levels accordingly, reducing the likelihood of shortages or delays in component deliveries due to disruptions. Overall, this measure contributed to strengthening Company A's supply chain resilience by improving visibility, communication and coordination across the whole supply network.

BOM - Bill Of Material Requirements

The case company implemented a measure requiring a bill of material from tier 1 suppliers to enhance their visibility within the supply chain. This measure aimed to

improve transparency and traceability by obtaining detailed information about the origins of components and their respective sub-suppliers. As explained by the Shortage Manager this was crucial to prioritize the components which is also a measure the company implemented that will be explained next.

''Focus more on Bill-Of-Material to have a better understanding on what components are included in the products and which ones are more crucial.''

- *(A1, Shortage Manager, personal communication, 2024)*

By requiring the submission of a bill of material, Company A wanted to gain insights into the entire supply chain, from tier 1 suppliers down to sub-suppliers, thereby mitigating risks associated with potential disruptions and ensuring greater accountability throughout the procurement process. This proactive approach enabled Company A to identify vulnerabilities and dependencies within its supply chain, facilitating more informed decision-making. Overall, the requirement for a bill of material from tier 1 suppliers played an important role in enhancing Company A's supply chain visibility and resilience, safeguarding its operations against unforeseen challenges and disruptions.

Strategic Buffer

Company A also established strategic buffers following the shortage crisis. Recognizing the vulnerability exposed by the crisis, Company A took steps to enhance its supply chain resilience by creating strategic buffers for critical components mostly electronics which contains semiconductors. This strategic buffer, implemented after the crisis, served as a safeguard against future disruptions, providing Company A with a safety level of inventory to mitigate the impact of unexpected supply chain disturbances. By strategically positioning buffers at key points in the supply chain, Company A aimed to minimize stockouts and maintain production continuity even in the face of unforeseen disruptions. In one of the interviews an interesting topic accrued where one of the managers pointed out Just-In-Time strategy being mainly used in the automotive industry. As in respondent mentioned;

''Before the crises a lot of companies within automotive used the Just-In-Time strategy for their production, including ours. Both for economical reason and difficulties to maintain storages. So another measure we applied was building buffers for components that are critical for the production, post-shortages when we had enough components for the production.''

- *(A1, Shortage Manager, personal communication, 2024)*

Moreover, the establishment of strategic buffers enabled Company A to respond more effectively to fluctuations in demand and supply, thereby enhancing its overall supply chain agility and responsiveness.

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