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IFAC PapersOnLine 55-10 (2022) 476–483

The Global Semiconductor Chip Shortage: Causes, Implications, and Potential Remedies

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Abstract: Since 2020, there has been a major supply shortage of semiconductors across the globe with no end in sight. As almost all modern devices and electronics require semiconductors, many industries are struggling to meet strong consumer demand. The covid pandemic is not only to blame for this shortage, for instance the semiconductor supply chain contained already many vulnerabilities and weak points that were merely exasperated by the current situation. In this paper, an overview of the semiconductor supply chain is performed with a focus on its main vulnerabilities. The main reasons behind the shortages are discussed and the impacts on many industries are examined. Finally, recommendations and remedies are suggested.

Keywords: semiconductor supply chain, semiconductor shortage, semiconductor crisis, supply chain disruptions, supply chain resilience, supply chain visibility

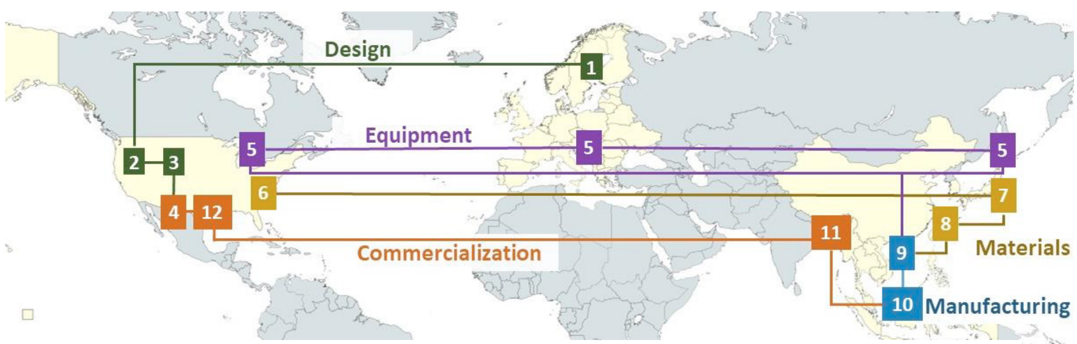

Figure 3: A Simplified Outlook on the Global SSC inspired from (Varas et al., 2021).

1. INTRODUCTION

Nowadays, semiconductors are very critical to many industries spanning from military and defense, electrotechnology, automotive, healthcare, entertainment and toys, among countless other applications. In fact, semiconductors are considered the “brains” of most modern devices and electronics. Since 2020, there have been serious supply shortages of semiconductors across the entire globe leading to what is referred to as the “semiconductor shortage crisis” considered by many experts as the modern version of the 70’s oil crisis. Indeed, countless products have been canceled, halted, delayed, and their prices have skyrocketed. Many industries were severely affected and there seems to be no end in sight for the crisis yet.

There are many reasons behind the crisis, with the COVID-19 pandemic being cited as the main one. However, the Semiconductor Supply Chain (SSC) has always had many vulnerabilities that were laying under the surface; the Covid-19 pandemic has just thoroughly exasperated them. This paper aims to explore the reasons behind the semiconductors’ global shortage, the impact of this shortage, and suggest some remedies and recommendations that may alleviate the situation. There are two relevant reviews covering the semiconductor shortage, namely: (Rumbaugh et al., 2020) and (Casper et al., 2021). However, none of them explores the reasons behind this semiconductor crisis or its impacts in depth. This review is unique in its kind because it is the first to delve deep into the reasons behind the shortage, provide real examples of the impacts, and provide different solutions for this crisis for the future.

The remainder of the paper is organized as follows. Section 2 gives a brief yet concise overview of the SSC, highlighting some very important resilience-related features. Section 3 summarizes the impact faced by some of the main industries in the wake of this crisis. Section 4 lists and discusses the main reasons and drivers of the shortage, while Section 5 suggests some recommendations and remedies. Finally, Section 6 provides takeaways and concluding remarks.

2. SEMICONDUCTOR SUPPLY CHAIN OVERVIEW

The World Semiconductor Trade Statistics (WSTS, 2021), estimated that the global semiconductor market is worth $553 billion, with a projected growth rate of 25.6% in 2021., This is considered the biggest increase since the 31.8% increase in 2010. Figure 1 shows the distribution of the semiconductor industry's demand drivers, as provided by the Semiconductor Industry Association (SIA, 2021a). Computers (32.3%), communication (31.2%), consumer (12.0%), industrial

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2022.09.439

(12.0%), automotive (11.4%), and government (1.0%) were the five main demand drivers for semiconductors in 2020.

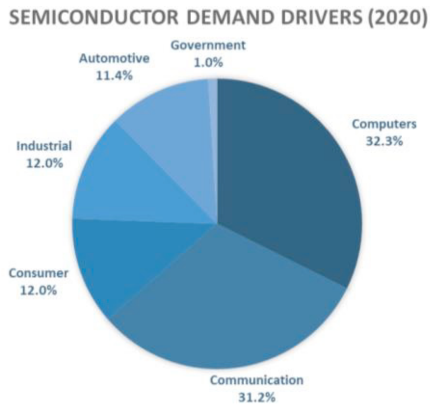

Figure 1: Semiconductor Demand Drivers in 2020 (SIA, 2021a)

As summarized in Figure 2, the SSC consists of four main steps: Pre-competitive research, Chip design, Wafer fabrication (front-end manufacturing), and Assembly, packaging & testing (back-end manufacturing). These steps are supported by a highly specialized environment consisting of: materials, equipment and tools, advanced electronic design automation (EDA) software, and architectural building blocks, which are referred to as intellectual property (IP) core blocks (Varas et al., 2021).

Every activity in this value chain requires considerable specialization and offers an opportunity to add significant value. Few supply chains exhibit an ecosystem that is as complex, intertwined, and widespread geographically as the SSC (SIA, 2016). On average, around 25 countries are involved in the direct supply of each segment of the semiconductor value chain. Before making it to the end consumer, one semiconductor product may cross international borders around 70 times (S. Alam et al., 2020).

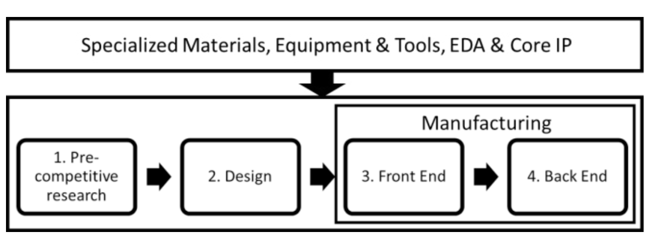

Figure 2: The Semiconductor Value Chain (Varas et al., 2021)

There are six main participants of the total global output of the semiconductor industry: US, China, Taiwan, South Korea, Japan, and Europe (Varas et al., 2021). The SSC is designed this way to get the maximum benefit from the diverse and unique skills of these different participants. An illustration of the global SSC is illustrated in Figure 3, which shows a typical journey of a semiconductor. Design and high-end manufacturing are usually done in the US, Canada and European countries. Raw materials are usually supplied from Japan, the US and some European countries. Companies in the US, Japan, and Europe, specialize in developing highly advanced equipment. As for manufacturing, assembling, testing, and packaging, it is usually done in China, Taiwan, Malaysia, and other Asian countries (SIA, 2016).

As per the above facts, one can conclude that the SSC is quite centralized, where design is concentrated in one area, and manufacturing is concentrated in another area. For instance, about 75% of the manufacturing capacity and needed key materials are located in China and East Asia. In addition, 92% of the world's most advanced manufacturing capacity of semiconductors are located in Taiwan (Varas et al., 2021). The value chain contains regional clusters for individual components. For instance, in almost all semiconductor products, polymeric material is used and is primarily manufactured in Japan, Taiwan and South Korea. This create a vulnerability in the SSC since there is a high concentration of a crucial component in a specific region (Hales et al., 2021).

According to Deloitte (2021), the majority of the top chip design companies rely on Asia Pacific region to manufacture their semiconductor chips. Over 70% of the total semiconductor manufacturing is collectively owned by the two most influential chip manufacturers: TSMC (Taiwan) and Samsung (South Korea). By 2020, Taiwan and South Korea accounted for the majority of the total semiconductor contract manufacturing (Duncan Stewart et al., 2021). More than 60% of the world's assembly, packaging and testing capacity is accounted for by mainland China and Taiwan (SIA, 2021a).

3. IMPACT ON INDUSTRIES

There has been a major impact on many businesses and industries. According to (Gopani, 2022), over 169 sectors and consumer lines were affected by the semiconductor shortage. From the perspective of each demand driver illustrated in Figure 1, the impact on these industries is discussed in this section.

4.1. Computers

In order to cope with the lockdown during the pandemic, people began to work from home, learn on Zoom, and watch shows on Netflix, resulting in a huge increase in demand for laptops and tablets (Knight, 2021). Component shortages and other supply challenges occurred from the spike in demand in the PC market (IDC, 2021). The global semiconductor shortage has caused lead times to be prolonged by as much as 120 days for some PC models, resulting in price increases in the bill of materials, which were passed on to customers (Kaur, 2021). With COVID-19 vaccinations becoming more accessible by the public, consumer and educational expenditure shifted away from computers towards other priorities, slowing the market's progress (Gartner, 2021b).

Due to a demand decrease for the Chromebook in the education market, HP saw a 30 percent drop in shipments. Furthermore, HP had a large number of unfilled orders, resulting in a missed opportunity to its competitors (Gartner, 2021b). Due to component shortages, Intel reported a 5% drop in revenue from notebook sales. On the plus side, their desktop PC sector saw a 20% increase in revenue. However, it was insufficient to make up for the notebook sales losses (Gartenberg, 2021).

4.2 Communication

The lack of semiconductor chips has greatly affected the smartphone industry, reducing planned production volumes. In 2020, smartphone sales fell by 12.5% (Gartner, 2021a), and prices are projected to continue rising (Goswami, 2021). According to Counterpoint (2021), the semiconductor scarcity has affected 90% of the smartphone industry. Many smartphone suppliers have made large component orders by the end of 2020. However, most smartphone manufacturers reported only receiving 80% of their order requests.

Samsung canceled the Galaxy Note series due of a semiconductor shortage (Adhikari, 2021). China's Xiaomi has lost more than 30% of its worth in 2021 owing to the semiconductor scarcity (Bloomberg News, 2021). Meanwhile, Huawei dropped to No.2 behind Apple, the biggest drop among the top five smartphone-makers (Gartner, 2021a). Apple, on the other hand, is doing well despite the present chip scarcity situation (Goswami, 2021). Even with the semiconductor shortages, this smartphone business grew due to proactive planning, order placement, as well as hoarding some high-value critical components (Counterpoint, 2021).

4.3 Consumer

TV prices have risen by almost 30% in the recent months of 2021, directly linked to the chip supply situation. In fact, devices that require display-bound integrated circuits are difficult to develop due to requiring older type of chips. Those less advanced chips are created in facilities that have not been upgraded to match current demand (Knight, 2021). Cameras rely on semiconductors as well. Sony's new ZV-E10 Mirrorless Vlogging Camera has been suspended due to the scarcity of semiconductors. Fujifilm, Nikon, and Canon are also affected. Canon's EOS R3 Mirrorless Camera has experienced shipping delays of up to 6 months during 2021 (Thubron, 2021).

Another victim of the semiconductor shortage are printer manufacturers. Canon has released instructions for consumers on how to bypass its Digital Rights Management (DRM) protocols when using their printers. DRM in ink cartridges is a way to discourage consumers from purchasing third-party ink cartridges; usually the printers will display error messages when inserting ink cartridges not manufactured by Canon. With the semiconductor chip shortage, Canon was forced to manufacture printers that cannot identify their own cartridges. Canon had to resort to telling its own customers to bypass the error message when refilling their ink cartridges, which is something consumers already did when purchasing ink cartridges from third-party sellers that are much cheaper (Gault, 2022).

The chip shortages have also harmed the gaming business. Valve's Steam Deck mobile gaming PC was originally scheduled to launch in December 2021, but has now been postponed until February 2022 (Peters, 2021). A forecasted 1.5 million reduction in Nintendo Switch sales was anticipated by November 4, 2021. Due to component and logistics challenges, Sony's PlayStation 5 target output has been cut from 16 million units to around 14.8 million units. The PS5 was released in the year 2020 and has been hard to find in stores since then. Because vaccination accessibility varies by country, chip supplies have been inconsistent. As a result, some gamers purchased PC editions of some PlayStation games (Mochizuki, 2021).

4.4 Industrial

Semiconductors are also vital to many sectors, including the healthcare sector for instance. Many medical equipment designed for specific applications require semiconductors. In an event of supply shortages, this type of equipment cannot be substituted with anything else, as they are not commodities easily replaced. One example of the semiconductor shortage impact was noticeable for manufacturers of medical ventilators. In 2020, there was over 9 million components of unmet demand, which was indicated by ventilator manufacturers (SIA, 2020).

The Internet of Things (IoT) industry has also been significantly impacted by the chip shortage. Around 80% of the global manufacturers are struggling in producing digital products, which require semiconductors. The advancement and development of this technology has been hindered as a result (Gregersen, 2021). There has been a major decline in AI performance breakthroughs, due to specialized hardware shortage that needed unavailable semiconductors. In fact, AI model architectures are evolving much faster than new AI chips hit the market, making the new models and available semiconductor compatibility obsolete (Ceze, 2021).

4.5. Automotive

The scarcity of modern automobile "brains" has severely affected the automotive supply chain. The semiconductor shortage might cost the US $61 billion in sales in 2021. Cars are nowadays viewed as “computers on wheels,” with electronics accounting for 40% of a car's value (Nicholas et al., 2021). An estimated $210 million will be lost on auto sales globally in 2021 (Takezawa, 2021). The chip scarcity has forced automakers to build and then park unfinished automobiles until they have received the required chips. In addition, some cars were offered to buyers without some usual features (Lienert, 2021).

The global manufacturing of the world’s No. 1 carmaker Toyota fell from 845,107 units last year to 627,452 this year, resulting in around 20% decline in sales (Takezawa, 2021). Volkswagen AG experienced the lowest drop in sales in the past decade due to the semiconductor shortage as well (Raymunt, 2022). Honda dropped production by roughly 4,000 cars in one Japanese factory, while Ford shutdown two plants in Kentucky and Germany (Nicholas et al., 2021). General Motors has reactivated plants that had been offline since mid-summer 2021 and is currently inserting chips into automobiles that were previously parked unfinished. This resulted in clients purchasing 2021 vehicles as 2022 models were also going into sale (Tucker, 2021).

Most automakers use Just-in-Time (JIT) planning; only preparing for the next week or month. Even with the current issues, they are hesitant to abandon their lean production practices because the benefits outweigh the drawbacks. In this example, the benefits of lowering inventory through lean tactics outweigh the costs of rare disruptions like the current chip shortage (Nicholas et al., 2021). Tesla, BMW, and Porsche reduced the number of options in their car models requiring semiconductor chips, in order to cope with the chip scarcity. Touchscreens, multi-adjustable chairs, and USB ports are examples of trimmed features (Gastelu, 2021).

4.6. Government

A report by the White House states how the government has been affected by the shortage, as semiconductors are essential in many ways including defense and aerospace, telecommunications networks, energy and utilities, healthcare, and financial services. One of the central roles of the semiconductor is being a vital part of national security. They enable the development of advanced weaponry and critical infrastructure. Virtually every military system requires semiconductors in their operations, which include communication and navigation systems (The White House, 2021a).

4. REASONS OF SSC SHORTAGE

The reasons behind the semiconductor shortage could be grouped into three main categories shown in Figure 4 and are discussed in this section.

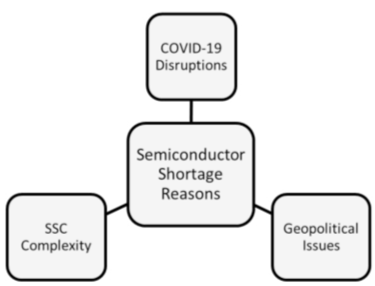

Figure 4: Main Semiconductor Shortage Reasons

3.1 COVID-19 Disruptions

No industry has been immune to COVID-19 implications and the semiconductor industry was no different. The revenue projection of the semiconductor industry has been overall decreased by $55.0 billion in 2020, during the peak of the pandemic. Along with this, there has been three main disruptions: Demand, Supply and Workforce disruptions (Accenture, 2020).

Demand disruptions included the sudden surge in demand of Working from Home (WFH) products such as laptops, tablets, smart home devices, etc., and a decrease in demand for consumer electronics, such as smart phones, due to loss of income (Accenture, 2020). Due to the pandemic in 2020, auto parts suppliers shut down facilities to mitigate the spread of the virus and canceled their chip orders to limit their inventory costs in anticipation of a drop in vehicle demand (The White House, 2021b), which resulted in a sudden variation in demand. As a result, many suppliers sought out other markets that were still thriving despite the pandemic. These included the main eight cloud infrastructure providers, who saw a demand surge for WFH products (Shein, 2021).

Supply disruptions included the forced closure of chip manufacturing plants due to global lockdowns (Ravi, 2020; Ro, 2020), resulting in the depletion of semiconductors production and inventory (Peters, 2021). Other supply disruptions were due to logistic-related issues. During the pandemic, the reduced amount of flights and closure of airports meant there were delayed chip shipments. Items related to COVID-19 were being shipped worldwide, which took up a lot of capacity. This resulted in engine failure in some airplanes, due to increased pressure on their cargo capacity. Overall, air cargo capacity in 2020 declined by 20% (S. F. Alam et al., 2021).

Workforce disruptions included the sudden requirement for quick and massive shift to WFH. This in turn resulted in the need for remote working tools as well as workforce flexibility. The extended time in quarantine also negatively affected employee morale. On the positive side however, this started a new level of workforce flexibility (Accenture, 2020) which could in turn help improve the robustness of the SSC overall.

3.2 SSC Complexity

The COVID-19 pandemic has only exacerbated the current situation, however, the SSC is inherently challenging and facing issues as it is highly complex in nature. Unique challenges faced in this case include long fabrication cycle times, a lot of variability and stochasticity, and non-linear manufacturing processes (Sun & Rose, 2015). Semiconductors are exceptionally difficult to produce. In fact, making these chips is one of the most R&D intensive manufacturing processes to exist. At such a miniature scale, highly specialized inputs and equipment are required to achieve the needed precision. Up to 1,400 process steps in the manufacturing of a semiconductor may be needed depending on the complexity of the chip (SIA, 2021b).

The average manufacturing cycle time of a semiconductor may take up to 26 weeks. To begin with, around 12 weeks are required to manufacture the semiconductor wafer; however, this might take up to 20 week for advanced processes. The next procedure is called back-end assembly, test, and packaging (ATP) which may take up to 6 weeks. This is illustrated in Figure 5. Ultimately, the lead-time between a customer placing an order and receiving the final product, may take up to 26 weeks (SIA, 2021b).

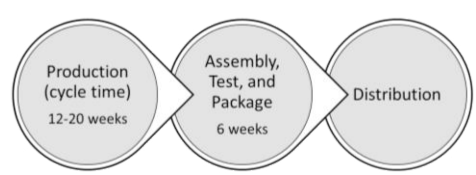

Figure 5: Semiconductor Production Timescales from (SIA, 2021b)

In addition to being a complex process, it is also very capital intensive, the fabrication of an entire wafer can cost up to $10 billion due to extremely expensive machines, each costing up to $100 million (Mönch et al., 2018a). Currently, with the market demand running high, capacity utilization of semiconductor fabrication facilities are already higher than

80% with some reaching 90-100% (SIA, 2021b). Increasing capacity however, is time consuming and expensive as expansion could take up to 9 months (Alam et al., 2021). Additionally, a solution found for one type of wafer fabrication, might not be applicable for the rest of the supply chain (Mönch et al., 2018a).

The SSC also spans over wide geographical areas. Its manufacturing facilities are distributed across different continents and into several different countries. Consequently, it needs to deal with different tax laws, import controls and diverse regulations (Mönch et al., 2018b). Furthermore, the geographic specialization mentioned in Section 2, has many positive aspects for the semiconductor industry mainly to take large advantage of economies of scale. However, activities being highly concentrated in certain regions has ultimately created two types of vulnerabilities: (1) Large scale disruptions can occur because of single points of failure, (2) Global access to suppliers or customers can be impaired due to geopolitical tensions (SIA, 2021a). Due to the SSC being highly globalized, disruptions happening in one region may cause bottlenecks in other region, (SIA, 2020).

3.3 Geopolitical Issues

Geopolitical tensions have globally risen in the past decade. In July 2019, Japan imposed restrictions on exports to South Korea following Korean court rulings against some Japanese businesses. This was a major concern for South Korea, as three key chemicals needed for semiconductor manufacturing were mainly imported from Japan. These are namely hydrogen fluoride, fluorinated polyimide and photoresists. During 2020, these tensions have eased with Japan approving export requests for these three chemicals; however, the situation is still sensitive (Varas et al., 2021).

In the meantime, the US and China have been locked in a “trade war” initiated by the previous US administration and whose objective is to make semiconductor manufacturing in China difficult. For instance, just last September, the US imposed export restrictions on the Semiconductor Manufacturing International Corporation (SMIC), the largest semiconductor firm in China, (Hoffower et al., 2021).

Currently, the only current viable suppliers of EDA and critical equipment are US companies as they are effectively blocking Chinese companies from sourcing semiconductors. This will have negative impacts for China’s advanced chip production in the short run. However, China is the biggest market for the US in terms of the semiconductor industry. In the long run, this will mean a significant loss of revenue from the Chinese market (Purkayastha, 2021). Additionally, this may trigger a retaliation from China, especially since this country has rare earth materials needed such as germanium, lithium or tungsten (Varas et al., 2021).

5. RECOMMENDATIONS AND REMMEDIES

Despite the global supply chain running at full capacity, the semiconductor shortage crisis is expected to persist well into 2022 (Dohner, 2022). The SSC must try matching supply and demand by improving its resilience and flexibility. In this section, a brief overview of government reactions are given, and then some recommendations and remedies are discussed.

5.1. Government Reactions

Governments are currently pushing to increase local semiconductor supplies to guard against future shortages. Through a process called “localization”, the United States, China, and European Union, have made commitments to increase their semiconductor manufacturing capacity (Duncan Stewart et al., 2021). According to (Joseph, 2021) governments around the world are attempting to solve this issue by investing in local semiconductor manufacturing facilities and increasing their semiconductor research funding. In addition, there has been policy interventions by governments around the world in an attempt to deal with this crisis, summarized in Table 1.

Table 1. Government Policies and Interventions to deal with the semiconductor shortage crisis, (Joseph, 2021)

Region	Policy/Intervention
United States	Innovation and Competition Act aim to spend $52 billion over the semiconductor industry
European Union	European Chips Act aims to accelerate the development of semiconductors
South Korea	Spend $451 billion on domestic semiconductor production
Taiwan	Invest $100 billion to meet the rising demand of semiconductors and expand its semiconductor foundry in Arizona, US
Japan	Semiconductors and Digital Industry Policy to increase production share of semiconductors and introduce new fabrication factories
India	Facilitate semiconductor manufacturing start-ups by introducing ‘Semiconductor Startup Incubation and Acceleration Programme’

5.2. Creating a Resilient SSC

Diversify crucial components of the supply chain.
More than 65% of the global market share could be held within one region across 50 points in the SSC supply chain, regardless of the region’s level of risk. All of these regions are considered as single points of failure as there could be disruptions caused by natural disasters, geopolitical tensions, shutdowns, etc. (Varas et al., 2021).

One company that successfully dealt with the chip shortage crisis is Tesla. While many automobile manufacturers struggled, Tesla has thrived, increasing its car sales in 2021 by 100% from 2020. Despite shutting down a plant briefly, the company has emerged as a successful case study on how to deal with the chip shortage. This is due to the company producing chips in-house, and has been responsive enough to re-write some software to work better with alternative manufacturers. Other brands such as Apple has also announced they will be producing their chips in-house (Gopani, 2022). The takeaway lesson here is to increase supply chain flexibility. By producing some chips in house, and having products compatible with different types of chips according to availability, supply chain resilience can be significantly improved.

According to (Varas et al., 2021), the pursuit of complete self-sufficiency is not the solution to these challenges as it incredibly costly and its feasibility is questionable. In an extreme hypothetical scenario, they presented what complete "self-sufficiency" looks like and must consist of, including having local firms in EDA and IP cores, deign semiconductors, manufacture all specialized equipment, have all raw materials, carry out front-end and back-end manufacturing, and ensure enough capacity to meet 100% of domestic demand for semiconductors across all applications. According to their analysis, this would cost $900 to 1,225 billion at a global level, which is a staggering cost aside from it having questionable feasibility.

There are many reasons why this extreme hypothetical scenario is very difficult to accomplish. An equivalent 40% of the existing global capacity has to be built, resulting in a massive overcapacity. Capacity of each region needed to cover the entire local semiconductor requirements, including raw material production, manufacturing of wafers, assembly, packaging and testing, can incur over $800 billion in capital expenditure. Assuming a region is able to acquire the funding needed, building facilities will take years and 3000 to 6000 employees will be required to operate them, mostly skilled technicians and staff. With at least 30 types of semiconductors available in the market, each region would need to be able to replicate its competitors in all semiconductor types. In addition to other costs, such as replicating manufacturing equipment as well as EDA and core IP (Varas et al., 2021).

Strengthening the resilience of the SSC should be the goal through targeted policies that expand open trade and balance the needs to national security. Building a SSC that is less vulnerable to disruptions require additional manufacturing capacity in the US and Europe, which creates a more diversified global footprint. Alternatives (domestic or third countries) should be developed for critical areas in the SSC threatened by disruptions (Varas et al., 2021). Reshoring crucial outsourced components must also be considered in this case (Hales et al., 2021).

Expansion of local capacity is essential in addressing major vulnerabilities in the SSC. For instance, it would allow the US to meet the necessary domestic demand for national security systems, aerospace, and critical infrastructure while other demand could be covered by third party manufacturers. Aiming to cover the entire US semiconductor demand would cost over one trillion dollars over ten years (Varas et al., 2021), which is inefficient and costly. In this way, SSC should try to achieve the perfect balance between producing onshore and offshore depending on the country's needs.

Manufacturing improvements.
Semiconductor manufacturing is complex and increasing capacity is extremely costly and takes years. However, there are methods that can be used to improve the current situation. New emerging technology such as Artificial Intelligence (AI) can be very useful in reducing lead times of chip production. Chip production process can be significantly reduced and done entirely by AI. While it takes 6 months for humans to build one processor, AI can do it in less time (Gopani, 2022).

In order to optimize efficiency, many semiconductor supply chains were built on JIT concept with the assumption that everything will be running smoothly as usual. However, this recent crisis has demonstrated how JIT can have devastating impacts under supply chain disruptions. For instance, a $30 chip shortage can stop the entire production line of a car worth $30,000, which suggests that the threat of the semiconductor shortage outweighs the benefit of the JIT principle in this type of supply chain (S. Alam, 2021). Manufacturers must amend their inventory polices in the long term to include more buffer stock for emergencies (Bowman, 2021).

Enhance visibility through digitization.
IoT has been cited as a creative solution for semiconductor shortage. Disruptions can be predicted through real-time data sharing and analysis. Furthermore, problems can be identified ahead of time and dealt with accordingly, improving the efficiency and resilience of the supply chain (Gregersen, 2021). Manufacturers are able to make sophisticated decisions based on collected information and making use of data elements that were in siloed applications previously. End-to-end performance can be improved from IoT analytics throughout the SSC including demand forecasts, production, scheduling, and inventory control (Black, 2021). AI can also scan for chip defects in real time (Gopani, 2022), improving quality control processes.

Dell's digitized supply chain has helped in dealing with the semiconductor shortage. Supply and demand scenarios are simulated in their digital model, allowing them to make decisions to either prioritize or cut down on certain SKUs when supply is running low. More companies are turning to digitization with the aim of increasing their supply chain agility in order to respond quickly to demand and supply volatility (Zimmerman, 2021).

6. CONCLUSIONS

The SSC is extremely vital in today's world and has been constantly evolving into an ever-increasing specialized value chain. Along with its growth, its complexity has also increased. Recent disruptions such as COVID-19 had devastating impacts, as the SSC vulnerabilities got exasperated during the past two years. Industries all over the world suffered these consequences, however some excelled in approaching this new challenge. Ultimately, building a resilient supply chain is the way forward in order to eliminate or minimize impacts of such disruptions. Therefore, future work must aim to first quantify SSC resilience and find areas where improvements can lead to the greatest increase in its resilience.

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