The Impact of the Computer Chip Supply Shortage

Hannah Casper, Autumn Rexford, David Riegel, Amanda Robinson, Emily Martin and Mohamed Awwad
Department of Industrial and Manufacturing Engineering
California Polytechnic State University
San Luis Obispo, CA 93407, USA
hcasper@calpoly.edu, Abrexfor@calpoly.edu, driegel@calpoly.edu, arobin21@calpoly.edu, emart148@calpoly.edu, mawwad@calpoly.edu

Abstract
The goal of this research is to explore solutions to recent shortages in the computer chip supply chain. The COVID-19 pandemic revealed weakness in the supply chain for computer chips. With more industries needing computer chips for their products, particularly the automotive industry, a shortage caused by shutdowns in China after the pandemic led to a rise in prices of consumer goods. In this research, we focus on the technicalities of the computer chip supply chain to find methods of preventing shortages and improving the overall supply chain to avoid future shortages. This is particularly important with the increased dependence on computer chips in products. India has shown success with its government incentives to encourage reshoring of computer chip manufacturing, so there is less dependence on other countries to obtain chips. It is recommended that the US follow India's lead and encourage reshoring of computer chip manufacturing to reduce the likelihood of shortages in the future.

Keywords
Computer Chip, Semiconductor, Fabless Foundry, COVID-19, Manufacturing Supply Chain

1. Introduction
A global shortage of computer chips has driven the cost of several products up and has limited production in industries such as automotive. The use of computer chips has become widespread across different industries, with each industry attempting to secure its own supply. Automakers only account for 10 percent of the total volume of semiconductors, leaving automakers with little leverage to secure chip supplies compared to other industries. Because of this, the automotive industry has struggled to obtain chips during the COVID-19 pandemic, forcing production halts and factory closures. (Doerfler 2021). The pandemic has highlighted the fragility of the computer chip supply chain and the necessity of creating a stable supply chain for the future. The goal of this research is to see how companies can best manage their supply chain to maintain a steady supply of computer chips for their products. This research seeks to achieve this goal by looking into computer chip technology and the technical aspects of the supply chain, causes of the shortage, and methods utilized in other cases to help supply chains adapt to a shortage.

1.1 Objectives
The research done in this paper can be used to determine how microchips can be readily available in non-vertical supply chains. The motivation behind this is to ensure that main sources of waste like waiting and overprocessing do not occur due to using outdated microchips that are readily available because the newest versions are not. Also, in the technological world of today, everyone relies on each other for some step of the process—and the computer chip supply chain has over 1,000 steps just in manufacturing. This paper explains why the shortage is occurring and dives deep into how a few countries specifically are impacting the supply chain of computer chips.

2. Literature Review
2.1 Computer Chip Technology
Nowadays, it is nearly impossible to get through a day without using some sort of technology, and all modern-day technology has a chip embedded in it somewhere. They act as the memory units and processors of information and are very tiny integrated circuits, also known as wafers. Computer chips are used in phones, cars, televisions, GPS devices, ID cards, and people are even implanting them in their hands to perform tasks around their house, like opening a wine cellar or accessing a safe. These tasks can occur due to the nature of how microchips are processed: transistors act as mini electrical switches to turn a current on or off (Kohls et al. 2020). Depending on how many microchips are

within a computer (or phone, or car, etc.), the processing power is determined. They are the perfect example of something that is small but mighty, and according to Moore's Law, they are only getting smaller. This is important to note because as they half in size, it means twice as many chips can fit into the same space as they once did.

2.2 Computer Chip Manufacturing / Supply Chain

This next section highlights how semiconductors are manufactured, goes over the long production lead time it takes to complete, and discusses why fab foundries may be the future when it comes to keeping up with demand.

2.2.1 Semiconductor Production Steps and Components

Production of semiconductors occurs in three major steps: design, fabrication, and ATP. ATP stands for assembly, testing, and packaging. (Khan et al. 2021). There are multiple components required to produce semiconductors. The first component needed for semiconductor fabrication is materials such as silicon or other semiconducting materials, which are used to create wafers, and photoresist, which is used to create circuit patterns on the wafer. The next component needed to produce semiconductors is semiconductor manufacturing equipment or SME. SME includes deposition equipment, etching equipment, photolithography equipment, and much more. Another component in semiconductor fabrication is core intellectual property (IP). "Core IP consists of reusable modular portions of designs, allowing design firms to license and incorporate them in their designs" (Khan et al. 2021). The final component of semiconductor fabrication is electronic design automation (EDA) which is computer software used in the chip design phase. Figure 1 displays the production steps, inputs, and manufacturing methods which are discussed in the following section.

2.2.2 Semiconductor Manufacturing Methods

There are a few different ways semiconductors commonly get manufactured. Some companies have a single location where they do all three of the production steps: design, fabrication, and ATP. These are referred to as integrated device manufacturers or IDMs for short. The IDM model is a vertically integrated business model and was popular in the technology boom of the 1970s. Rapid technological progress has greatly increased manufacturing costs for semiconductor technology, and these high manufacturing costs create high barriers to entry for semiconductor manufacturing. The high costs associated with manufacturing semiconductors led to the eventual creation of fabless foundries so smaller design firms could focus on design and let someone else carry the burden of manufacturing costs. In addition, globalization has spurred the onset of fabless firms as companies take advantage of low manufacturing costs from Asian fabs and import the finished goods back to the United States. The vertically integrated model that IDMs employ inhibits their ability to manufacturer the latest technology. Keeping up with the latest technology requires large capital investments that are hard to come by in a company that is both designing and fabricating (Mulay 2017).

Fabless firms and foundries are the norm for many US companies. Fabless firms design and sell the chips, but they outsource them to a foundry to be fabricated and send them to an outsourced semiconductor assembly and test (OSAT) firm for ATP (Khan et al. 2021). Fabless companies in the past had to tap into the excess capacity of IDMs for manufacturing. Fabless companies could often not afford to own their own fab due to the intensive capital investments required. High barriers to entry and frustration with outsourcing to IDMs led to the creation of dedicated foundries. The fabless-foundry model greatly lowers the barrier to entry and spurred the rapid growth of fabless companies (Hung et al. 2017).

Taiwan Semiconductor Manufacturing Company (TSMC) created the first dedicated semiconductor foundry that focused solely on manufacturing. TSMC is contracted by large companies like Apple to produce the chips companies design. Dedicated foundries do not have to sell products or compete with customers, creating a focus on technological development. Foundries can take the demand of multiple fabless companies in addition to providing extra capacity to IDMs in need. The fabless-foundry model also creates shared development costs which have a great impact on operational efficiency. The mutual relationship between fabless companies and dedicated foundries has become increasingly popular and competitive to the traditional IDM model (Hung et al. 2017). Intel recently announced its IDM 2.0 vision which combines expanding third-party foundry capacity with the creation of its own dedicated foundry company, Intel Foundry Services. Intel's model addresses the need for more US semiconductor manufacturing capacity while also taking advantage of dedicated foundries outside the US, integrating IDM and the fabless-foundry model (Intel 2021).

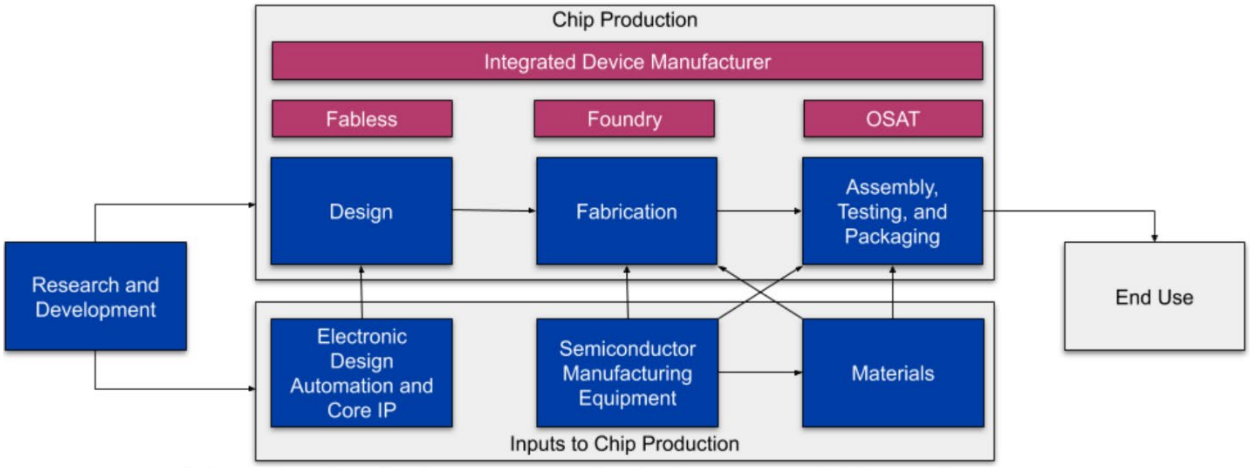

Figure 1. The semiconductor supply chain (Khan et al. 2021)

2.2.4 Current State of Semiconductor Supply Chain

According to the Center for Security and Emerging Technology (CSET) in the 2021 CSET Issue Brief titled "The Semiconductor Supply Chain: Assessing National Competitiveness," different countries specialize in varying segments of the semiconductor supply chain. "The United States dominates in R&D and has strong capabilities across all segments," but it lacks firms in photolithography tools and foundries. South Korea, on the other hand, produces large amounts of materials, some SME, and specializes in all production steps. "Taiwan is dominant on the most advanced manufacturing and ATP and produces some materials" (Khan et al. 2021). Europe and Japan specialize in SME and materials. Europe also specializes in core IP, and Japan "produces many older technology semiconductors" as well. China struggles in inputs for production such as SME, Core IP, EDA, and some manufacturing materials, but is strong in ATP, raw materials, and tools for assembly and packaging.

2.2.6 Semiconductor Manufacturing in India

India is a leader in semiconductor R&D but lacks a strong fab infrastructure. Fabs require large upfront investments, copious amounts of water, a large uninterrupted power supply, and the availability of key resources such as silicon. Shortages of key resources and weak infrastructure have led India to focus on R&D and the design of semiconductors. There is a large talent pool of IT design and R&D engineers that have cultivated a multi-billion-dollar semiconductor design market in India. However, the Indian government is looking to seriously invest in semiconductor manufacturing to remain competitive on a global scale. Constructing fabs is very capital intensive, which has led the Indian government to look for foreign capital to fund new fab operations in India (Kapur 2021).

The Indian government currently has three government-owned fab facilities that manufacture solely for defense and space needs. Producing chips for commercial applications is lagging and is the current policy focus. The Indian government has made policy decisions to encourage growth in semiconductor design and manufacturing, such as providing initial capital and creating investment incentives (Mamidala 2021). The Ministry of Electronics and Information technology recently issued an Expression of Interest (EOI) to promote the growth of fabs in India and the acquisition of fabs outside the country. The EOI calls for applicants to submit proposals to set up or expand fabs in India or to facilitate acquisitions of facilities outside of India (Kapur 2021). Another example of a policy is the performance-linked incentive (PLI) policy which offers participating manufacturers cash-back for exports. Apple is a major company taking advantage of the program and plans to expand iPhone manufacturing in the country over the next five years (Phartiyal 2020).

2.3 Causes and Impact of the shortage

This section discusses the many factors that led to the computer chip shortage and the impact of the shortage in the car manufacturing industry.

2.3.1 Increased Demand for Semiconductors

With recent trends in automotive safety, autonomous driving, and connectivity comes a huge spike in demand for semiconductors. On average, a new automobile consists of ~3,500 semiconductors each in order to account for new autonomous driving features such as parallel parking, cruise control, enhanced cameras, and more. With the eventual shift to fully autonomous driving, analysts suspect that the sales of automotive semiconductors will increase by 6% annually, a 4% difference from the average growth from 1995 to 2015 (see Figure 2 below) (Burghardt et al. 2017). However, with the production slashes caused by pandemic shutdowns, supply cannot keep up with demand.

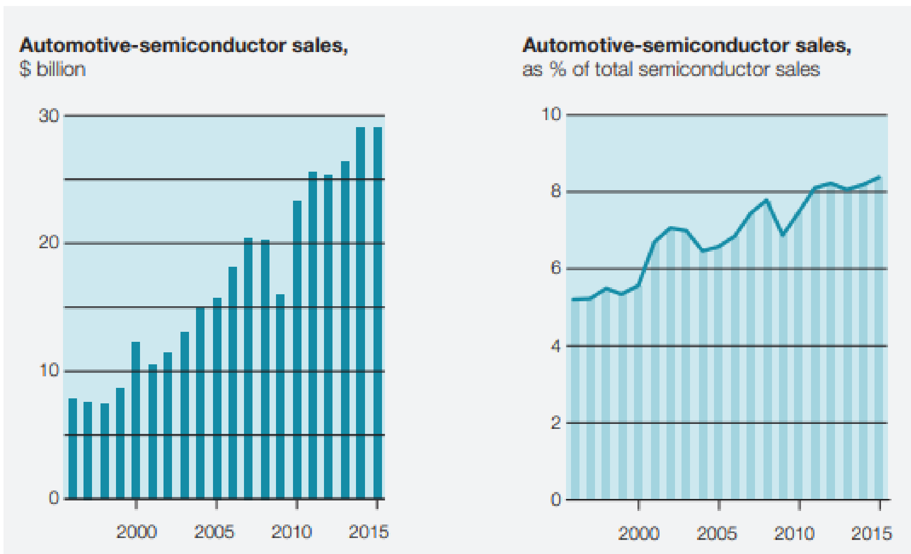

Figure 2. Automotive-semiconductor sales (Burghardt et al. 2017)

2.3.2 COVID-19 Shutdowns

With COVID-19 finally striking US soil and a national lockdown in mid-March of 2020, economists believed that consumer spending would dwindle down as people were losing jobs and buying less non-essential products; thus, automotive companies stopped purchasing new semiconductors and halted their production lines. With less automotive demand, semiconductor companies shifted their supply to the rising demand for other electronic products such as TVs, video games, and computers due to the recent stay-at home orders.

2.3.3 Impact

After a couple of months, the demand for semiconductors for automobiles rose quicker than anyone expected as seen in Figure 3 below. With a lead time of around 26 weeks, it is almost impossible to bring supply back to the levels of demand immediately--leaving thousands of WIP vehicles solely in need of semiconductors (Falan 2021).

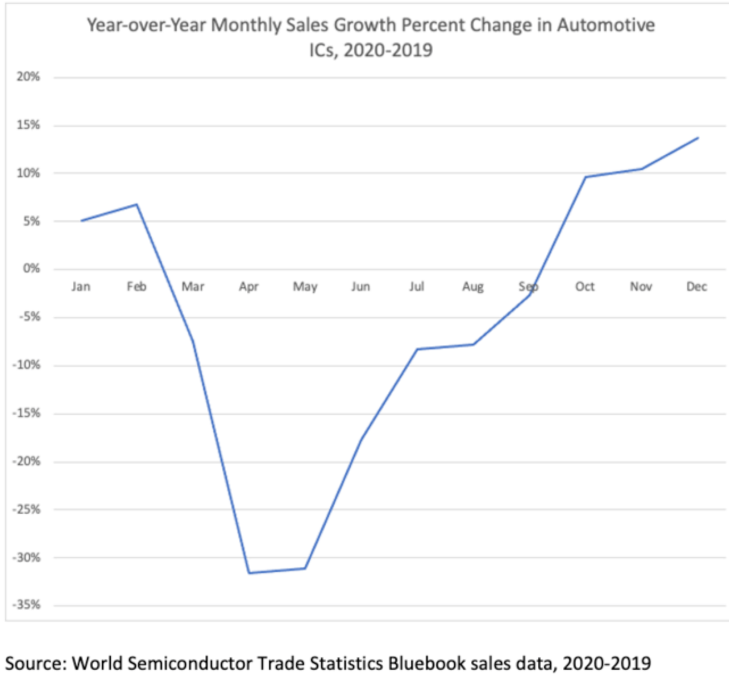

Figure 3. 2019-2020 Monthly Sales Growth Change in Automotive ICs (Falan 2021)

This shortage opened the eyes of the United States' government. A bi-partisan letter from eight Governors was sent to President Biden on February 26th, 2021, expressing their concerns of the semiconductor shortage. The governers' requested that President Biden follow suit like other foreign countries and "reallocate a modest portion of their current production to auto-grade wafer production" (WP Company 2021). Furthermore, they stated that these automakers and suppliers provide hundreds of jobs and are a staple in the recovery of the economy post-COVID-19. This prompted President Biden to immediately and seriously reconsider America's supply chain and its vulnerabilities through a 100-day review. As there are improvements to be made, the following section highlights how improvements have been made elsewhere.

2.4 Supply Chain Improvements for Shortages

The next section of literature investigates successful strategies to help supply chains deal with a shortage.

2.4.1 Reshoring

One method explored reshoring production in response to global emergencies. This was valuable since a large contributing factor to the shortage in the computer chip industry was the COVID-19 pandemic (CNBC 2021). In the past, many companies have used offshoring production to reduce the cost of producing their goods. This provided less expensive labor and production costs. However, since the beginning of 2020 and the COVID-19 pandemic, China's production shutdowns were detrimental to many businesses that had taken their production overseas. Reshoring production can create improvements that may help in the event of a shortage. For one, it is much easier to control production aspects like quality and control processes for onshore manufacturing. There are also fewer governmental restrictions when production is held onshore. There are also benefits for the local community when manufacturing is done locally. And finally, reshoring production is more sustainable as there is much less travel distance for a supply chain network (Fromm et al. 2020).

2.4.2 Mathematical Models and Analytical Approaches

The next area of research involved ways to incorporate shortages into mathematical models so that the optimal supply chain can be designed in a quantitative manner. One model developed a stochastic programming approach that incorporated a shortage function into their model. This specific cost function was unique because instead of using a linear cost function, they used breakpoints to increase the cost of unit shortage as the shortage number increases. As seen in Figure 4 below, this led to a reduced frequency of shortages in their model (S.M.J. Mirzapour Al-e-hashem et al. 2013).

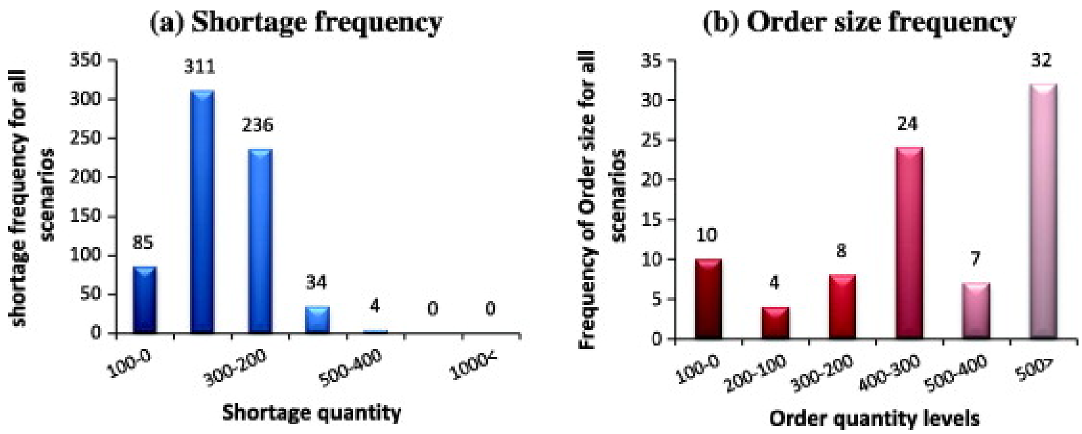

Figure 4. Shortage and order size frequencies under different scenarios (S.M.J. Mirzapour Al-e-hashem et al. 2013)

Another issue when incorporating other factors into a mathematical model is giving a solver too many parameters to deal with, so finding an optimal solution can become difficult or impossible. Another source suggests utilizing a new clustering algorithm to organize different solutions and find an optimal solution when there are more parameters and functions added to a model, like shortages in this case (Sasan 2015). The process flowchart for this algorithm is included in Figure 5 below.

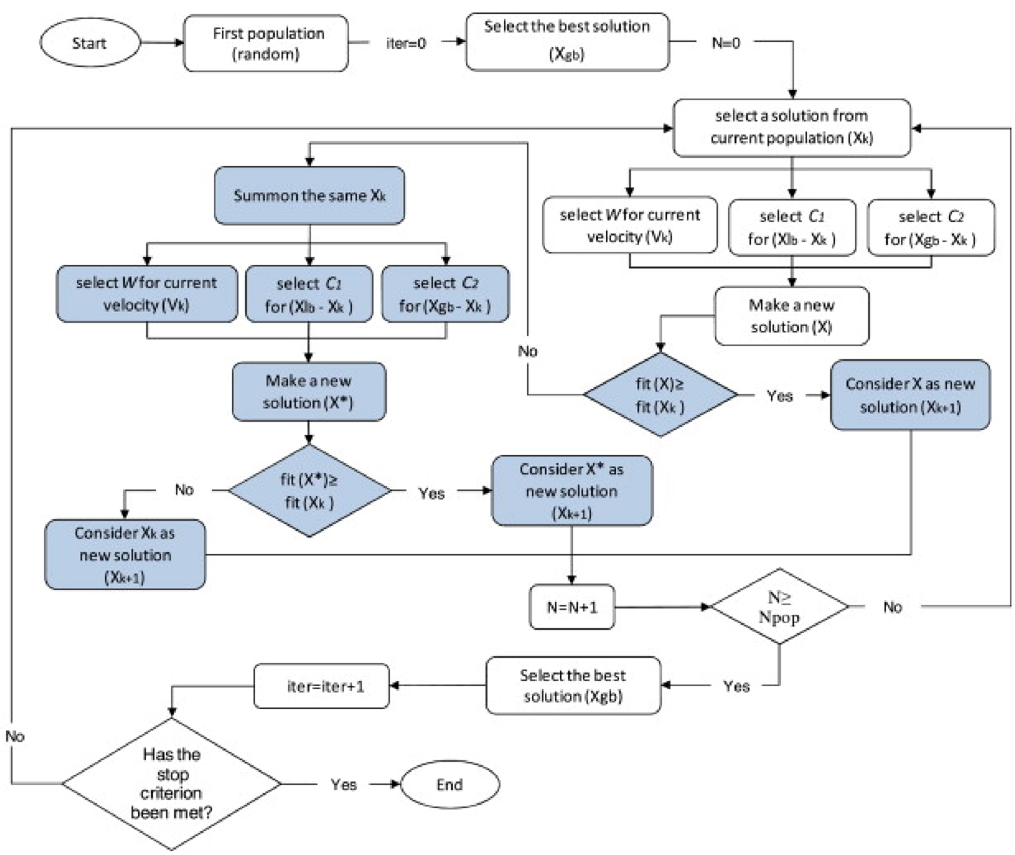

Figure 5. Flowchart of Comparative Particle Swarm Optimization (Sasan 2015).

This is a useful method to apply in analytical models for optimizing supply chains to try and incorporate more factors into a model without making the model too data or time-consuming to solve. These tools that have been used to improve supply chains in the context of shortages in other industries and scenarios helped us to develop methods that may be effective in the case of the computer chip shortage.

3. Methods

All research came from online sources such as journals, articles, and books. Much of the information comes from large organizations like the Center for Security and Emerging Technology (CSET), IEEE, the Semiconductor Industry Association (SIA), and others that have large collections of journals on supply chain and engineering topics. It is important to note that chip manufacturing is a rapidly changing topic and is happing all over the world, making conducting research on this industry as a whole very difficult. To account for this, most of the resources are from the last few years, with some even from this year to verify that the data is current and relevant.

4. Results and Discussion

Computer chips are an integral part of modern technology. A large percentage of everyday devices and products rely on chips to function, causing chip shortages to create large ripples through the global supply chain. The three major steps of semiconductor production include design, fabrication, and ATP. Semiconductor production requires a ready supply of silicon or other semiconducting materials in addition to reliable, large sources of water and electricity. Semiconductors are manufactured by means of three methods: integrated device manufacturers (IDMs), fabless, and dedicated foundries. IDMs have had trouble increasing capacity and keeping up with the rapid technological innovation of dedicated foundries. Fabless manufacturers and dedicated foundries have teamed up to create the fabless-foundry model, eliminating some of the barriers to entry for smaller design firms. The fabless-foundry model is a trend that is increasingly popular and has led IDMs to rethink their business model. Although the U.S. is a leader in semiconductor R&D, the US is lacking in fab infrastructure and increasingly relies on dedicated foundries in other countries like Taiwan. Taiwan's TSMC has taken advantage of the dedicated foundry model to rapidly scale up production and focus on chip manufacturing innovation.

One up-and-coming country in the semiconductor Industry is India. Similar to the U.S., India has a strong R&D and IT sector that is a dominant power in semiconductor design. India lacks a strong infrastructure to support fab facilities. However, India's government is becoming a possible model for other countries lacking in fabs with an increased policy focus on encouraging semiconductor industry growth. India's government is offering strong incentives for foreign investment to build a more robust fab infrastructure in an attempt to solidify India's place as a major player in the future of the semiconductor industry.

Chips play an increasingly important role across industries and sectors. One example is the automotive industry and the push for electric vehicles. Regular vehicles already require a large number of chips to function with modern technology, but the goal of all-electric vehicles will require a steady and large chip supply to sustain the electric goals of the country. As chip requirements rise for vehicles, the consumer electronics industry also is increasingly reliant on chips to meet the demand for personal electronics such as phones and laptops. Multiple industries are battling to take their share of a limited chip supply, necessitating the need for a more reliable and diverse semiconductor supply chain to meet increasing demand.

One method to improve the semiconductor supply chain is reshoring production. IDMs and fabless companies alike have taken advantage of cheap manufacturing costs abroad for chip fabrication. However, when global crises arise, less vertically integrated supply chains can have problems ensuring a stable supply of chips with manufacturing spread out overseas. A more analytical approach has also been discussed utilizing mathematical models to analyze shortage frequency. Mathematical models can be used to optimize supply chain design while decreasing shortage frequency.

Another strategic player in improving supply chains is the government. Countries like India are using incentive-based programs to attract foreign capital in addition to crafting policy to encourage technological development in the semiconductor industry. The US is forming a task force to see what can be done to increase the capabilities of US-based fabs and stabilize the semiconductor supply chain. Government can play a key role in creating policy and programs to facilitate a strong technological infrastructure and encourage in-country fabrication.

5. Conclusion

COVID-19 has brought awareness to the necessity of restructuring the US semiconductor supply chain. Offshoring of chip fabrication has made the US dependent on other countries for production. During normal times, the offshoring of production has been largely beneficial to US fabless companies and IDMs looking to outsource the cost of manufacturing to other entities. However, COVID-19-induced supply chain issues caused US shortages in key chips necessary for manufacturing everything from cars to laptops. The US is strong in design and R&D but lacks the fabrication infrastructure necessary to ensure a steady in-country supply of chips for domestic use.

The US chip shortage has halted production in industries such as automotive, even as demand is at an all-time high. As automobiles transfer to be completely autonomous and electric, semiconductors are drastically rising in demand, and the country's supply lines heavily rely on other countries such as Taiwan, Japan, and Europe for semiconductor supply. This reliance is detrimental, as any disasters such as COVID-19 or increased tensions with these countries can completely halt the supply chain. Chip shortages have also affected the cellular industry as networks upgrade to 5G. Chips are necessities for developing the 5G infrastructure cellular providers need to fully roll out 5G across the country. In addition, consumer demand for 5G phones and laptops is increasing rapidly, and a steady supply of chips is necessary to keep up with this demand (Leprince-Ringuet, 2021).

To ensure a steady future supply of chips, it is recommended that the US Government provide incentives for in-country manufacturing and reshoring of production. The US should consider following the lead of countries such as India, which use government policies to incentivize computer-chip manufacturers to re-shore and ramp up production. This will reduce reliance on other countries, as well as bring more sustainability and regulation to the supply chain and jobs back to the states. It is also recommended that the US explore the use of mathematical models to optimize the current supply and reduce the frequency of shortages. The research discussed in this paper is not exclusive and is ongoing. The state of the semiconductor supply chain is continuously evolving, necessitating further research on best practices for maintaining a steady chip supply. Future research is needed on effective government policy for incentivizing in-country fabrication, in addition to developing methods for diversification of semiconductor supply chains. Furthermore, research is needed on the future of IDMs and what they can do to remain competitive with the rise of the fabless-foundry model.

References

Burghardt, S., Choi, S., Weig, F., 2017. Mobility trends: What's ahead for automotive semiconductors. McKinsey&Company. https://www.mckinsey.de/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/Mobility%20trends%20Whats%20ahead%20for%20automotive%20semiconductors/Mobility-trends-Whats-ahead-for-automotive-semiconductors.pdf

CSET, 3–7. https://doi.org/10.51593/20190016

Doerfler, Sue. (2021). "Global Chip Shortage Necessitates' Fundamental Rethinking'." *Ismworld*. www.ismworld.org/supply-management-news-and-reports/news-publications/inside-supply-management-magazine/blog/2021/2021-05/global-chip-shortage-necessitates-fundamental-rethinking/?utm_campaign=shareaholic.

Falan, Yinug. (2021). *Semiconductor Shortage Highlights Need to Strengthen U.S. Chip Manufacturing, Research*. Semiconductor Industry Association. https://www.semiconductors.org/semiconductor-shortage-highlights need-to-strengthen-u-s-chip-manufacturing-research/.Was this referenced?

CNBC*, How The Global Computer Chip Shortage Happened*. (2021, February 26). [Video]. YouTube.

Hung, H.-C., Chiu, Y.-C., Wu, M.-C., 2017. Analysis of Competition Between IDM and Fabless–Foundry Business Models in the Semiconductor Industry. IEEE Transactions on Semiconductor Manufacturing 30, 254–260. doi:10.1109/tsm.2017.2699739

"Intel CEO Announces 'IDM 2.0' Strategy for Manufacturing, Innovation,..." *Intel*, 23 Mar. 2021, www.intel.com/content/www/us/en/newsroom/news/idm-manufacturing-innovation-product-leadership.html.

Kapur, Yashoda. (2021). "Setting Up a Semiconductor Fabrication Plant in India: What Foreign Investors Should Know." *India Briefing News*. www.india-briefing.com/news/setting-up-a-semiconductor-fabrication-plant-in-india-what-foreign-investors-should-know-22009.html/.

Khan, S., Mann, A., & Peterson, D. (2021). The Semiconductor Supply Chain: Assessing National Competitiveness.

Kohls, R. T., Grassel, J. T., Dolan, B. M., & Awwad, M. (2020). Analytical model for production planning in integrated circuit supply chains. *IIE Annual Conference Proceedings*, 544-549. Retrieved from https://er.lib.k-state.edu/login?url=https://www.proquest.com/scholarly-journals/analytical-model-production-planning-integrated/docview/2511379344/se-2?accountid=11789

Leprince-Ringuet, Daphne. "The Impact of the Global Chip Shortage Continues to Ripple across the Tech Supply Chain." *ZDNet*, ZDNet, 10 May 2021, www.zdnet.com/article/the-impact-of-the-global-chip-shortage-continues-to-ripple-across-the-tech-supply-chain/.

Mamidala Jagadesh Kumar (2021) Is India going to be a major hub of semiconductor chip manufacturing?, IETE Technical Review, 38:3, 279-281, DOI: 10.1080/02564602.2021.1916166

Mulay, Apek. (2017). *How the Information Revolution Remade Business and the Economy: a Roadmap for Progress of the Semiconductor Industry*. Business Expert Press.

Phartiyal, Sankalp. (2020). "Three Top Apple Suppliers to Commit $900 Million to India Smartphone Incentive Plan - Sources." *Reuters*. www.reuters.com/article/india-smartphone-manufacturing/three-top-apple-suppliers-to-commit-900-million-to-india-smartphone-incentive-plan-sources-idUSKBN26J1TJ.

Sasan Khalifehzadeh, Mehdi Seifbarghy, Bahman Naderi, A four-echelon supply chain network design with shortage: Mathematical modeling and solution methods, *Journal of Manufacturing System*s, vol 35, 2015, pp 164-175, 2015.

S.M.J. Mirzapour Al-e-hashem, A. Baboli, Z. Sazvar (2013), A stochastic aggregate production planning model in a green supply chain: Considering flexible lead times, nonlinear purchase and shortage cost functions, *European Journal of Operational Research*, vol 230, no. 1, pp. 26-41.

WP Company. (n.d.). *Governors' letter to President Biden requesting help with semiconductor shortage hobbling auto industry*. The Washington Post. https://www.washingtonpost.com/context/governors-letter-to-president-biden-requesting-help-with-semiconductor-shortage-hobbling-auto-industry/3d3a42c3-fa0f-437b-b4e7-a4f43d213849/?itid=lk_inline_manual_7.

Biographies

Hannah Casper is a fourth-year student at Cal Poly pursuing a blended Bachelor's and Master's in Industrial Engineering and minoring in Statistics. Hannah has had previous internship experiences in data analytics and enterprise architecture, both in the health care industry. This Summer, Hannah plans to join Western Digital's RAMP Operations on their procurement team. Hannah has had other research showcased with IEOM Zimbabwe on blockchain-enabled supply chain for Cal Poly's wine. She has continued pursuing this area of research with her thesis topic quantifying the benefit of the blockchain-enabled supply chain.

Autumn Rexford is a fourth-year Industrial Engineering student at Cal Poly, San Luis Obispo, graduating this June 2021. She has a passion for process improvement and change management. Autumn has previous intern experience in a variety of industries, including engineering consulting with Jenike & Johanson, distribution and warehousing with Target, and the topic of this paper, chip manufacturing with Corning Inc. After graduation, Autumn will be starting a full-time position as an Operations Industrial Engineer with the United States Postal Service in the Bay Area of California.

David Riegel is a fourth-year Industrial Engineering student at Cal Poly, San Luis Obispo, graduating this June 2021. David has had a previous internship with his home-town brewery, South Lake Brewing Company (SLBC) where he implemented a QR code tracking system for their keg inventory. After graduation, he will be returning to work with SLBC over the summer to prepare and implement their management system to account for the opening of a new location.

Amanda Robinson is a fourth-year Industrial Engineering student at Cal Poly, San Luis Obispo, graduating this June. Amanda loves working with people to bring about lasting and impactful change. She previously worked as a Master Data intern with Atlas Copco Mafi-Trench, working to standardize a material master database and implement process improvements to increase factory efficiency. After graduation, Amanda will be working full-time as an Industrial Engineer with Atlas Copco in Santa Maria, CA.

Emily Martin is a fifth-year Industrial Engineering student at Cal Poly, San Luis Obispo, graduating June 2021. She transferred to Cal Poly in 2018 from a small, liberal arts college in the Midwest. Emily is passionate about implementing process improvements, teaching emotional intelligence, and getting more women and girls involved in STEM. She has been previously published for UAV research and last summer interned at NASA Jet Propulsion Laboratory in the Mechanical Inspection group of Quality Assurance. Following graduation, she will work there as a full-time Process Improvement Engineer.

Mohamed Awwad is an Assistant Professor in the Department of Industrial and Manufacturing Engineering at California Polytechnic State University (Cal Poly), San Luis Obispo, CA. He received his Ph.D. and M.S. degrees in Industrial Engineering from the University of Central Florida, Orlando, FL, USA. Additionally, he holds M.S. and B.S. degrees in Mechanical Engineering from Cairo University, Egypt. Before joining Cal Poly, San Luis Obispo, Dr. Awwad held several teaching and research positions at the State University of New York at Buffalo (SUNY Buffalo), the University of Missouri, Florida Polytechnic University, and the University of Central Florida. His research and teaching interests include applied operations research, logistics & supply chain, blockchain technology, distribution center design, unconventional logistics systems design, and Operation Research applications in healthcare and the military.