

The Evolution of Purchasing Models in the Semiconductor Supply Chain: A Literature Review

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Received May 29, 2025, **Revised:** June 20, 2025, **Accepted:** June 23, 2025, **Published Online:** June 29, 2025

Reviewers: Anonymous Peer Review

Citation: Johnson, L. L., Ebakivie, O., Johnson, S. M. (2025). The Evolution of Purchasing Models in the Semiconductor Supply Chain: A Literature Review. *International Journal of Supply Chain Management*, 14(3), 65-79, <https://doi.org/10.59160/ijscm.v14i3.6312>

Abstract— Semiconductors are crucial components of modern technology, with uses ranging from communications to national security. As demand for semiconductors rises, it is critical to understand procurement methods, which have a considerable impact on pricing and supply chain dynamics. The study provides an in-depth analysis of the literature on the evolution of purchasing models in the semiconductor industry, including historical and current viewpoints. It analyzes four key purchasing models: direct purchasing, distributor purchasing, value-added resellers (VAR), and online purchasing, each with unique strategic advantages and problems that impact buyer-supplier relationships, cost, and delivery consistency. This study contributes to the literature through providing a comprehensive review of the semiconductor supply chain while exploring available purchasing models and identifying factors that help shape purchasing decisions. The research delves into the historical development of various models, their current implementation, and potential future trends. Additionally, the research identifies existing gaps in the literature and suggests areas for future investigation to further enhance supply chain efficiency and effectiveness. The findings from this study will provide valuable insights for the semiconductor industry, offering strategies to optimize their supply chain, improve resilience, and adapt to emerging challenges.

Keywords— Supply chain management, semiconductor supply chain, purchasing models, procurement

1. Introduction

Semiconductors are often unseen and yet one of the most integral parts of the modernization of our

world. They are made from crystal solids of single or compounds of elements often found in groups III, IV, and V of the periodic table that possess special electrical characteristics that make them vital to the functioning of computers and the many other electronic devices used daily for leisure and precision work. These natural elements can conduct electricity under designed conditions [1]. The assembly of memory chips and many other components that enable core technologies such as the internet and GPS, as well as the emergence of Artificial Intelligence (AI), is a critical aspect of modern electronics. Memory chips, particularly those made with advanced packaging and integration processes, are critical for the effective processing and storing of data required by these technologies. For example, the introduction of 3D-packaging technology for stacked memory chips has considerably improved memory device performance and capacity, allowing for more advanced AI and GPS applications [2]. Furthermore, the advancement of AI is driving significant growth and new opportunities for semiconductor companies, particularly in the development of specialized hardware such as GPUs and ASICs for AI training and inference tasks in the cloud and on the edge [3]. Without the use of semiconductors, many of the tools used to improve everyday life, compete, and drive our financial markets, as well as the advancement of countries would not come to fruition in the time and efficient ways they have since the use and perfection of the semiconductor within our technology and systems.

As aforementioned, semiconductors are paramount for the advancement of nations through technology. They allow for improvements in national security, speed of communications, and the transferring of funds and payment instantaneously. Innovations in fabrication, characterization and manufacturing of semiconductors help power 5G and high-speed internet technologies. With its everyday use and practicality, the demand for these precious parts is at an all-time high [4].

With demand constantly growing, the methods in which buyers procure their semiconductors can have a cascading impact on pricing throughout the supply chain to the final consumers. The purchasing model chosen by the buyer ultimately determines the costs they pay and the timing and consistency of delivery of the semiconductors to the designated locations. The purchase model chosen may also directly impact the buyer-supplier relationship and affect the buyer's ability to determine the quality and price of the semiconductors [5], [6]. Four purchase models will be considered in this study and each of the purchase models can have an increased amount of variability and lack of dependability. Each may have its strategic value in specific scenarios as an answer to specific challenges in purchasing [7]. The choice of purchasing model can significantly influence supply chain resilience and performance.

The purpose of this paper is to explore and investigate the existing literature on purchase models used in the semiconductor industry. Examining traditional purchasing models aims to understand the trends of purchasing within the semiconductor industry, as well as the factors that are driving the change.

2. Methodology

This review study is designed to explore the evolution, current practices, and future directions of purchasing models within the semiconductor supply chain. The review employs a systematic approach to ensure the analysis is coherent and contributes valuable insights to both academic and industry discourse.

2.1 Research Strategy and Data Collection

The foundation of this study is built upon a robust research strategy, carefully designed to capture a wide spectrum of relevant literature. The primary objective of this strategy is to identify, select, and synthesize information from peer-reviewed academic articles and other credible sources that specifically address purchasing models in the semiconductor industry.

The search for relevant literature began with an extensive assessment of popular academic databases such as JSTOR, ProQuest, Taylor & Francis, and ScienceDirect. These databases were chosen for their extensive collections of academic publications and peer-reviewed articles, both of which are critical to guaranteeing the review's quality and dependability. To successfully capture the breadth of literature on the theme, an array of search terms and keywords were used. This included keywords such as "semiconductor," "purchase models," "supply chain," "procurement," "strategic purchasing," and "supplier management," among others. The keywords were used in a variety of combinations and configurations to ensure that the search was thorough and targeted, encompassing all facets of semiconductor supply chain management.

Given the scope of this review, the timeframe for the literature search was deliberately broad. While the primary focus was on studies conducted within the last 5-10 years to ensure the inclusion of the most current research and trends, the review also incorporated older articles that provide essential historical context. These foundational studies were deemed critical for understanding the evolution of purchasing models in the semiconductor industry, especially those that have had a lasting impact on current practices. All selected sources were rigorously vetted for credibility, with a strict preference for peer-reviewed articles and academic journals. To maintain the relevance, rigor, and quality of the review, specific inclusion and exclusion criteria were established as shown in Figure 1.

3. Literature Review

The development of semiconductor technology has been a journey of continuous innovation and discovery spanning nearly two centuries. Early 19th-century research on specific materials' peculiar electrical characteristics laid the foundation for the future study of semiconductor physics.

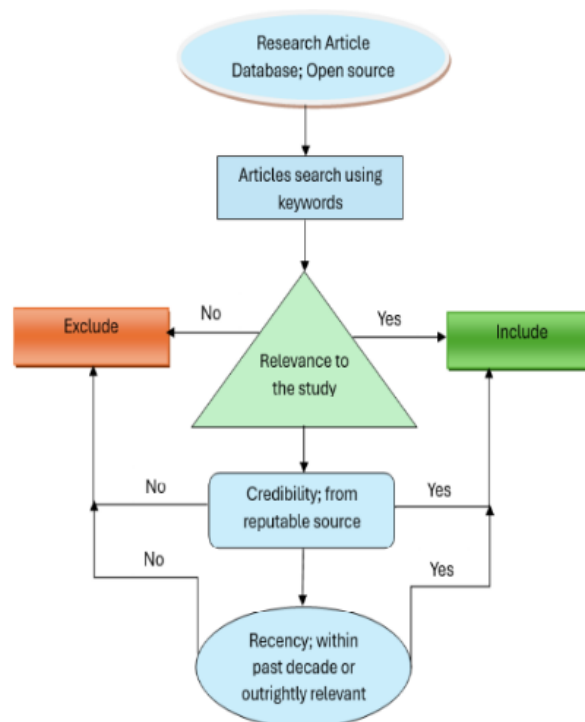


Figure 1. Article Selection: Inclusion and Exclusion Criteria for the Literature Reviewed

Michael Faraday made the first discovery in 1833 when he noticed that, in contrast to metals, the electrical conductivity of silver sulfide increased with temperature [8]. Late in the 19th century, scientists made important discoveries that opened new fields of study and real-world applications, such as Willoughby Smith's discovery of photoconductivity in selenium in 1873 and Karl Ferdinand Braun's identification of the rectifying effect in metal-semiconductor junctions in 1874 [9]. These early breakthroughs paved the way for rapid advancements in the 20th century.

The mid-20th century marked a watershed moment with the invention of the transistor. In 1947, John Bardeen, Walter Brattain, and William Shockley at Bell Labs developed the first working transistor, revolutionizing electronics by enabling the creation of smaller, more efficient, and reliable components [9]. This innovation paved the way for modern computing and communication systems, fundamentally altering the technological landscape. Because of its optimal electrical characteristics and abundance, silicon became the predominant semiconductor material throughout this time. Significant breakthroughs in integrated circuit technology were made possible by the capacity to create high-quality silicon crystals and control their properties at the atomic level, which fueled the expansion of the semiconductor industry [10].

The development of new materials, fabrication methods, and device architectures has allowed researchers to push the boundaries of what is feasible, resulting in an acceleration of semiconductor innovation in recent decades. From

smartphones to the supercomputer industry, the development of increasingly potent and energy-efficient electronic gadgets has been made possible by this continuous progress. These industries are faced with both opportunities and challenges as traditional silicon-based technologies near their physical limits. Exciting areas of exploration like quantum computing and two-dimensional materials have the potential to influence the direction of semiconductor technology in the future [11]. The development of semiconductors over time has demonstrated the inventiveness of people and the strength of scientific investigation, highlighting their vital role in advancing technology and revolutionizing modern-day living.

3.1 Operations Research Techniques

The semiconductor industry has benefited substantially from the cutting-edge research involving operations research and mathematical modeling techniques. IBM has utilized mixed integer programming techniques, queuing models, and heuristic methods to produce improvements in the semiconductor supply chain [12], [13], [14]. Manufacturing, one of the primary functional areas for semiconductor production, has been improved using linear programming tools and genetic algorithm solution tools, which allowed Intel to experience significant cost savings [15]. Research has also shown how optimization, statistical techniques, and inventory management strategies can improve performance in semiconductor supply chains and improve profits [16], [17].

3.2 Purchasing Models

Purchasing models have always been in everyday use, called by different names and strategic purposes. From early bartering to the invention and implementation of digital currency, purchasing power and its importance have been essential in shaping the way the world conducts every level of business. Over the past century, purchasing models has undergone significant transformation, driven by evolving business environments and technological advancements. Procurement was primarily seen as a support function, focused on minimizing costs, however over time securing quality materials has become a top priority for many industries [18]. In addition, companies are selecting more of an analytical approach to procurement to help achieve business goals and optimal outcomes.

Organizations started implementing increasingly complex supplier management and resource allocation techniques in the middle of the 20th century. Globalization and economic expansion following World War II led to significant advancements in purchasing models. The notion of strategic sourcing was first proposed in the 1960s and 1970s, focusing on quality enhancements and long-term supplier relationships while coordinating procurement choices with overarching corporate objectives.

Procurement procedures underwent a substantial transition in the 1980s and 1990s, with a focus on collaborative partnerships with suppliers. This led to the emergence of partnership-based models that prioritized long-term relationships, shared goals, and mutual benefits. The incorporation of Total Quality Management (TQM) principles, which encouraged continuous improvement and defect prevention throughout supply chains, had an impact on procurement during this time as well. At the same time, Just-In-Time (JIT) manufacturing gained popularity as a technique that prioritizes lowering inventory levels and improving productivity by closely coordinating suppliers [19], [20]. By encouraging more sustainable and effective methods, these modifications to procurement techniques had a significant impact on the development of contemporary supply chain management [21].

The late 1990s brought about a revolution in procurement through the advent of e-procurement

technologies. These online platforms facilitated more efficient transactions, real-time information exchange, and increased visibility across supply networks [22]. Enterprise Resource Planning (ERP) systems further integrated procurement with other business functions, providing real-time data and analytics to support decision-making processes [21].

In the early 2000s, procurement became a critical component of broader supply chain management strategies, emphasizing alignment with organizational goals and integration with various business functions. Globalization led to more sophisticated international sourcing strategies, requiring the management of complex cross-border transactions and regulatory environments [23]. In recent times, sustainability and social responsibility have gained prominence in procurement, with modern models incorporating environmental and ethical considerations into supplier selection and performance evaluations [24]. Advances in digital technologies, such as artificial intelligence, blockchain, and the Internet of Things, are further reshaping procurement practices by enhancing predictive capabilities, automating routine tasks, and promoting transparency and efficiency in supply chain operations [25]. The historical evolution of purchasing models underscores a dynamic field that continues to adapt to economic, technological, and strategic changes, offering valuable insights into future procurement practices.

3.3 Purchasing Models in the Semiconductor Industry

Over the years, various purchasing models have evolved, which have revolutionized the semiconductor industry's supply chain. Some of these models, their importance, and limitations are summarized in Table 1. Since the inception of the semiconductor industry, component purchasing has been primarily done through direct purchasing. This arrangement enabled purchasers to obtain semiconductors and other critical components directly from manufacturers, eliminating the costs associated with intermediaries. Direct Purchasing was valued for its cost-effectiveness, allowing purchasers to directly negotiate rates and impact

Table 1. Purchasing Models Relevance and Limitations

PURCHASING MODEL	IMPORTANCE	LIMITATION	REFERENCES
Direct Purchasing	Allows producers to keep direct control over the procurement process, guaranteeing alignment with specific requirements and direct communication with suppliers.	High reliance on supplier relationships with potential for supply chain disruptions if problems emerge.	Delke, Schiele, & Buchholz, 2023
Distributor Purchasing	Allows you easy access to a wide selection of products while also allowing flexibility and the option to purchase components from diverse manufacturers.	Higher costs may result from intermediary margins and probable response delays.	Uzsoy et al., 2018
Value Added Resellers (VARs)	Provides additional services like customization, installation, and support, which increases the value proposition for buyers.	May introduce complexity in the supply chain and additional costs for services that may not be necessary.	Ray et al., 2016
Online Purchasing Models	Digital platforms offer ease, speed, and cost advantages, particularly for standardized components.	Limited ability to manage complex or high-volume orders, as well as significant risks from online fraud.	Peng, Trappey, & Liu, 2005; Amoroso & Hunsinger, 2009; Golicic et al., 2002

expenses. This technique, however, needs buyers to have deep industry expertise as well as the capacity to create and sustain long-term relationships with suppliers. Buyers were at a disadvantage without such understanding, which is why professional intermediaries became so important [26]. Despite their lack of direct industry experience, these intermediaries used their specialist knowledge and connections to help manage the procurement process and guarantee that buyers acquired the necessary components.

As the semiconductor market grew and became more complex, particularly during the technology boom, the Distributor Purchasing model gained traction. This model involved buyers working through distributors who functioned as intermediaries between manufacturers and buyers. Distributors provided several benefits, including technical support, inventory management, and logistical services, which simplified the procurement process for buyers. This model became popular among those who lacked the expertise to negotiate directly with manufacturers or who needed access to a broad range of components. While the Distributor Purchasing model offered convenience and a range of value-added services, it often came at a higher cost compared to direct purchasing. The added cost was sometimes justified by the additional services provided, which could enhance the overall efficiency of the supply chain [27].

With the semiconductor industry's further maturation and the increasing demand for customized and niche products, the Value-Added Resellers (VARs) model emerged. VARs operated as intermediaries between distributors and buyers,

adding value by offering customization, integration, or additional services. This model was particularly beneficial for buyers needing specialized or niche components that were not available in standard configurations. VARs provided expertise and tailored solutions, which helped buyers gain a competitive edge. However, this model also introduced additional costs and longer lead times due to the extra steps involved in customization and integration. The presence of another intermediary in the supply chain meant that buyers had to balance the benefits of specialized services with the potential for increased costs and extended procurement times [28].

As the semiconductor industry continued to evolve, the rise of e-commerce and the increasing number of hobbyists led to the development of the Online Purchasing Model. This model was driven by the need for more accessible and cost-effective purchasing options. Online purchasing allows buyers to order components directly from manufacturers, distributors, or VARs via digital platforms. This model eliminated the need for traditional negotiations and contracts, providing a convenient, on-demand purchasing option. Buyers could use advanced search tools and review systems to make informed decisions quickly. However, this model also presented challenges, such as the risk of encountering counterfeit or substandard components due to lax regulations. The lack of direct, personalized technical support further complicated the purchasing process, as buyers had to rely on their knowledge and research to ensure the authenticity and quality of their purchases [29], [30].

While various purchasing models offer benefits, there remains substantial room for innovation and enhancement. As global supply chains grow more intricate and technological advancements continue to reshape industries, it is essential to evaluate how current models can be updated or combined to tackle emerging challenges. Technologies like artificial intelligence, blockchain, and big data hold promise for improving supply chains [31], but their specific role in shaping a purchasing model within the semiconductor supply chain is not yet fully explored. Additionally, understanding how these technologies can be integrated into existing models to optimize costs, quality, and lead times could yield valuable insights. Investigating ways to balance cost-effectiveness with the necessity for expert support in a dynamic, global market may offer new insights into purchasing strategies within the semiconductor supply chain.

4. Discussion of Current Landscape for Global Semiconductor Supply Chains

The global semiconductor supply chain is intricate and specialized, leading to a high degree of interdependence among companies worldwide. It consists of four primary stages: wafer production, semiconductor production, intermediate electronics, and final electronics. Different regions have specialized in various stages of this supply chain due to their technological capabilities. As highlighted by Ref. [32], the United States, the European Union, and Japan are mainly involved in the upstream segment, while Taiwan and South Korea are key players in the midsection, and China is prominent in the downstream segment.

In terms of raw material exports, the European Union accounts for a significant portion, providing about 30% of all raw material exports. Japan exports essential inputs like gases and chemicals needed for semiconductor manufacturing, with around 40% of these inputs traded globally during the wafer production phase. Taiwan and South Korea are responsible for producing about 35% of all traded semiconductor products, while China leads in manufacturing intermediate and final products. According to Ref. [33], the United States and Germany are the largest net exporters of raw materials, whereas Japan and China are leaders in wafer exports. Taiwan and South Korea are the primary exporters of semiconductors, with China being the largest consumer for manufacturing final electronics, which are then exported to the United States and other countries.

The COVID-19 pandemic significantly disrupted the semiconductor supply chain. Lockdowns and social distancing measures affected both the demand and supply of semiconductors. Anticipating a decline in vehicle demand, car manufacturers shut down plants and cancelled chip orders. However, the

manufacturing sector rebounded more quickly than expected, leading to a surge in demand once the pandemic was under control. This unexpected increase caught manufacturers off guard, as they had adjusted their purchasing models to focus on other industries. The 2020 semiconductor shortage impacted approximately 169 countries, with the automotive and consumer electronics sectors being the most affected [32].

Geopolitical tensions have significantly impacted global supply chains. In 2019, tensions between South Korea and Japan resulted in export restrictions on key components for semiconductor production. Japan, a major exporter of these inputs, and South Korea, a leading semiconductor producer, faced potential disruptions in their supply chains. The issue was resolved before causing significant damage [34]. Similarly, the technological rivalry between the United States and China has led to various shocks in the supply chain. Also, in 2020, the U.S. imposed trade restrictions on exports to a major Chinese semiconductor manufacturer. By 2022, the U.S. further restricted advanced manufacturing equipment technology exports to China and formed agreements with the Netherlands and Japan to control the export of raw materials and advanced equipment to China [35], [36]. These restrictions have wide-reaching impacts, given the significant roles these countries play in the global market.

The constantly evolving nature of the semiconductor supply chain and its unique vulnerability to various shocks has pushed most companies to develop a hybrid of multiple strategies to increase efficiency, manage risk, and reduce uncertainty as much as possible across the supply chain. Intel, which is one of the largest players in the semiconductor industry recently unveiled plans to increase partnerships and expand their supply chain outside the US to safeguard the corporation against uncertainties [34]. The corporation has received subsidies from the government to establish plants in Arizona and Ohio and plans to expand into areas like Germany, Poland, Israel, and Malaysia. Currently, the corporation develops exceptional units for personal computers and servers but lags Samsung and Taiwan Semiconductor Manufacturing Company (which is one of the largest contract chip makers) when it comes to the development of powerful, energy-saving chips.

NVIDIA has also proved to be a powerful rival when it comes to the development of chips for artificial intelligence, which is one of the fastest-growing industries in the technology sector. Since production is managed by the Taiwan Semiconductor Manufacturing Company (TSMC), the corporation's success has had a ripple effect in the industry. As one corporation in the supply chain begins to experience exponential growth as is the case for NVIDIA, corporations and suppliers are

exposed to new opportunities for growth. TSMC's increase in revenue has partially been driven by the robust performance of NVIDIA in the industry [37].

4.1 Globalization and Supply Chain Resilience in Semiconductor Procurement

Globalization has significantly transformed the semiconductor supply chain, presenting both challenges and opportunities for procurement strategies. Semiconductor companies now operate within a globalized market characterized by complex supply networks, diverse sourcing strategies, and intricate geopolitical dynamics. This globalization has served as both a catalyst and a challenge to supply chain resilience in semiconductor procurement [38]. To strengthen resilience, companies have adopted strategies such as diversifying their sourcing and manufacturing locations. For instance, major players like Samsung and SK Hynix have established production facilities across various countries, reducing their reliance on single-source suppliers and specific geographic regions, which ultimately enhances supply chain flexibility [39].

The COVID-19 pandemic has highlighted the critical importance of resilient supply chains, leading semiconductor companies to reevaluate their sourcing strategies and invest in digital technologies to enhance visibility and agility. Companies like Nvidia and Qualcomm have employed advanced analytics and real-time monitoring tools to better predict demand changes and adjust production schedules, ensuring continuity during disruptions [40]. Building strong collaborations and partnerships is essential for bolstering supply chain resilience. By engaging in collaborative innovation with strategic suppliers, semiconductor firms can access new technologies and valuable market insights. These partnerships, along with cooperation with industry stakeholders and government entities, contribute to the development of industry standards and risk mitigation strategies [41].

Adopting technology is crucial for improving supply chain resilience in the semiconductor sector. Digital tools such as blockchain, IoT, and artificial intelligence play a significant role in providing real-time visibility, traceability, and predictive analytics. Industry 4.0 technologies, in particular, have transformative potential, allowing companies to monitor performance, identify risks, and respond proactively to disruptions [42]. Additionally, navigating regulatory compliance and managing risks is vital in this global supply chain context. Semiconductor companies must address complex regulatory environments, including trade regulations, export controls, and intellectual property laws, to ensure compliance and reduce legal risks. Proactive risk management, including

risk assessments, scenario planning, and supply chain mapping, is essential for identifying vulnerabilities and protecting operations [43].

Strategic inventory management is crucial for managing the fluctuations in supply and demand in a globalized market. Semiconductor companies employ various strategies, such as demand forecasting, inventory optimization, and maintaining safety stock, to reduce the impact of supply disruptions and prevent stockouts. Implementing just-in-time (JIT) and lean inventory practices, along with strategic buffer stock, helps ensure a steady supply and meet customer demands even in volatile markets [44], [45]. By combining diversification, technological advancements, collaboration, and strategic inventory management, semiconductor companies can better manage the complexities of global supply chains and enhance their resilience against ongoing challenges.

4.2 Strategic Practices and Management in Semiconductor Supply Chains

Strategic purchasing practices are essential in the semiconductor industry, where rapid technological advancements and intense global competition necessitate sophisticated procurement strategies. These practices ensure that semiconductor companies can secure a reliable supply of high-quality materials, components, and services, which are crucial for maintaining the continuous production and innovation that the industry demands. As the industry faces frequent challenges such as fluctuating market demands, geopolitical tensions, and supply chain disruptions, strategic procurement becomes a key differentiator, allowing companies to maintain operational stability while fostering long-term growth and competitiveness [46]. Nevertheless, there are opportunities to explore how these practices can be adjusted to better address emerging challenges and capitalize on global market opportunities.

One of the foundational elements of strategic purchasing in the semiconductor industry is the rigorous process of supplier selection and qualification. Given the high precision required in semiconductor manufacturing, companies dedicate extensive resources to identifying and vetting suppliers that can meet their stringent technical, quality, and delivery standards. According to Ref. [47], this process is critical for ensuring that suppliers are not only capable of delivering consistent quality but are also financially stable and reliable. While existing research provides a strong understanding of these practices, exploring how supplier selection can be optimized in new and emerging markets remains a valuable pursuit.

Effective supplier relationship management (SRM) is another critical aspect of strategic purchasing in the semiconductor industry. Once

suppliers are selected, companies must actively manage these relationships to maximize value and drive innovation. Semiconductor companies often engage in joint development projects with their key suppliers, sharing technical knowledge and collaborating on product innovations. Although SRM practices are well-documented, examining how these partnerships evolve over time and under varying market conditions could reveal new insights, especially in the context of rapidly changing technological environments.

Risk management is another critical component of strategic purchasing in the semiconductor business. Because semiconductor supply chains are worldwide, businesses face a variety of risks, including geopolitical conflicts, natural disasters, and market volatility. According to Ref. [48], semiconductor businesses must implement proactive risk management techniques to identify potential supply chain vulnerabilities and build countermeasures to mitigate them. This includes doing regular risk assessments, scenario planning, and supply chain mapping to better understand the possible impact of various interruptions. Expanding our understanding of how businesses can better anticipate and reduce risks associated with global supply chain dynamics is critical, especially in lieu of recent global events that have created new challenges for supply chain resilience.

The influence of technological advancements on strategic purchasing practices in the semiconductor industry cannot be overstated. As digital technologies such as advanced analytics, artificial intelligence, and blockchain become more prevalent, they are transforming the way semiconductor companies approach procurement. Ref. [49] note that these technologies enable companies to gain deeper insights into market trends, demand patterns, and supplier performance, allowing for more informed decision-making. While current research highlights the benefits of these technologies, exploring how companies can integrate these tools more effectively into their procurement strategies, especially as technology continues to evolve rapidly, is of growing importance.

Sustainability and ethical sourcing are also increasing in importance as strategic purchasing strategies for semiconductor corporations. As global awareness of environmental, social, and governance (ESG) issues rises, businesses face increasing responsibility to guarantee that their supply chains are sustainable and ethical. This entails inspecting suppliers' practices to verify they comply with environmental regulations, labor standards, and ethical business practices. Companies are promoting responsible sourcing through a variety of methods, including the implementation of supplier codes of conduct, frequent audits, and the pursuit of sustainability certifications. Assessing the long-term

impact of these practices on overall supply chain performance and competitiveness, as well as their ability to fulfill changing stakeholder expectations, will be critical as the sector navigates these issues.

4.3 Strategic Outsourcing in Semiconductor Supply Chains

Strategic outsourcing plays a critical role in optimizing semiconductor supply chains, contributing to enhanced competitiveness by enabling companies to leverage specialized expertise, access innovative technologies, and improve cost efficiency. By forming strategic partnerships with external suppliers and service providers, semiconductor companies can focus on their core competencies while outsourcing non-core functions to trusted partners. For example, the partnership between Apple Inc. and Taiwan Semiconductor Manufacturing Company (TSMC) serves as a prominent case of strategic outsourcing. According to Ref. [50], Apple relies on TSMC for its semiconductor chip production, a relationship that grants Apple access to advanced manufacturing capabilities, ensuring a consistent supply of high-quality chips for its products. This alliance allows Apple to maintain its competitive edge in the consumer electronics market.

Similarly, NVIDIA Corporation uses strategic outsourcing to supplement its internal production capabilities. By cooperating with contract manufacturers such as Foxconn Technology Group, NVIDIA can easily scale manufacturing to meet the rising demand for its graphics processing units (GPUs) while focusing on innovation and product development. This method emphasizes the need for outsourcing to manage production capacity flexibly. Strategic outsourcing also makes it easier to have access to specialized technology and knowledge that might otherwise be unavailable internally. Advanced Micro Devices (AMD), for example, collaborates with third-party design firms to create customized semiconductor designs. This partnership demonstrates how outsourcing may foster technological innovation and expedite time-to-market for new products.

Moreover, strategic outsourcing allows semiconductor companies to optimize their cost structures, improving overall financial performance. By outsourcing logistics, warehousing, and distribution, companies can reduce overhead costs, enabling them to allocate more resources to core activities like research, development, and marketing [51]. This cost-effective approach contributes to enhanced profitability and shareholder value. Flexibility and scalability are additional benefits of strategic outsourcing, allowing semiconductor companies to respond swiftly to market dynamics and changing customer demands. According to Ref. [52], partnerships with contract manufacturers and

foundries enable companies to adjust production volumes in line with demand fluctuations, market trends, or regulatory changes, thereby maintaining a competitive edge. However, strategic outsourcing in the semiconductor industry is not without its challenges. Ref. [53], suggest that companies must manage supplier relationships carefully, ensure the protection of intellectual property, and address quality control and supply chain transparency concerns. Additionally, geopolitical factors, trade tensions, and supply chain disruptions can pose risks to the reliability and stability of outsourced operations. While the current strategies and models offer significant advantages, there remains a need to explore how companies can balance these benefits against emerging complexities in global supply chains, especially as technological advancements and geopolitical landscapes continue to evolve.

4.4 Supplier Relationship Management for Supply Chain Optimization

Supplier Relationship Management (SRM) is a foundational element in optimizing the supply chain within the semiconductor industry, where the complexity and rapid technological advancements demand close and strategic collaboration with suppliers. SRM involves developing and maintaining long-term relationships with key suppliers to foster collaboration, drive innovation, and create mutual value [54]. This approach ensures that semiconductor companies can secure a stable, efficient, and high-quality supply of materials, components, and services, which are crucial for the manufacturing of innovative products.

A pivotal aspect of SRM is the process of supplier selection and qualification. Given the intricate requirements of the semiconductor industry, companies invest substantial time and resources into identifying suppliers that can meet their stringent technical, quality, and delivery specifications. The supplier qualification process is rigorous, often involving a comprehensive assessment of the supplier's capabilities, track record, technological expertise, and financial stability [55]. This evaluation is crucial in ensuring that suppliers can reliably deliver the high-quality components essential for semiconductor manufacturing. By thoroughly vetting suppliers, companies can mitigate risks related to supply chain disruptions and enhance overall resilience.

Another crucial element of SRM in semiconductor procurement is proactive risk management and contingency planning. The dynamic structure of the global supply chain, combined with the high stakes in semiconductor production, involves identifying and evaluating potential risks. Ref. [54] emphasized the significance of building strong contingency strategies to address a variety of eventualities,

including supplier failures, geopolitical instability, and natural disasters. Semiconductor businesses often perform risk assessments, scenario planning, and supply chain mapping exercises to identify weaknesses and develop mitigation solutions. This proactive approach enables businesses to maintain supply chain continuity and avoid costly disruptions that could harm production and market competitiveness.

Transparent communication and information exchange are vital for the successful implementation of SRM. The semiconductor industry's reliance on precision and timing necessitates seamless communication channels between companies and their suppliers. Digital platforms and advanced collaboration tools are increasingly employed to streamline communication, share real-time data, and facilitate informed decision-making [56]. Cloud-based supplier portals are one such innovation, allowing suppliers to access up-to-date information, submit orders, and track deliveries, thereby enhancing visibility and coordination across the supply chain. These platforms not only improve operational efficiency but also strengthen the collaborative relationship between semiconductor companies and their suppliers.

An additional essential component of SRM is to foster a collaborative and trusting culture. Ref. [57] highlighted the value of developing strong, long-lasting relationships based on mutual respect, integrity, and transparency. Semiconductor firms understand that a successful SRM strategy takes more than just a transactional approach; it also necessitates a commitment to collaboration and common goals. Companies that nurture these connections are better positioned to fulfill their strategic goals while navigating the challenges of an increasingly complex supply chain. As the industry evolves, it is critical to grasp the dynamic nature of SRM in the face of rapid innovation and globalization.

4.4.1 Optimization and Ethical Considerations in Semiconductor Procurement

The semiconductor industry, situated at the intersection of advanced technology and intricate global markets, highlights the necessity of supply chain optimization for maintaining competitive advantage. Due to the industry's fast-paced environment, companies must continually refine their supply chain strategies to control costs, adapt to changing demands, and manage risks. Intel Corporation, a prominent player in semiconductor manufacturing, exemplifies this approach by meticulously optimizing its supply chain processes. Through strategic management of procurement, production schedules, and supplier relations, Intel can effectively respond to market changes while keeping inventory costs under control, thereby

aligning its supply chain operations with its broader business objectives [58].

In the semiconductor industry, accurately predicting demand is crucial for optimizing supply chain operations. Taiwan Semiconductor Manufacturing Company (TSMC), a major player in the semiconductor field, uses innovative analytics and machine learning tools to forecast demand with a high degree of accuracy. This capability allows TSMC to adjust its production schedules in real-time, ensuring that procurement processes are closely aligned with expected demand. This strategy not only boosts operational efficiency but also helps to avoid the costly issues of overproduction and stockouts, which are significant concerns in the semiconductor industry due to the rapid depreciation of inventory [31]. Efficient inventory management is another vital component of optimizing semiconductor supply chains. Companies like Samsung Electronics utilize just-in-time (JIT) inventory methods to minimize holding costs and improve cash flow. By maintaining low inventory levels and relying on up-to-the-minute demand data, Samsung can quickly adapt to changes in the market, thereby reducing the financial risks associated with having too much or too little stock. This approach not only enhances financial outcomes but also aligns with lean manufacturing principles, which focus on maximizing efficiency and minimizing waste [27]. In the semiconductor industry, where profit margins can be slim, such strategies are essential for sustaining profitability.

Supplier relationships play a pivotal role in semiconductor procurement, influencing both the stability and efficiency of the supply chain. Apple Inc., for example, has developed close collaborations with key suppliers such as TSMC and Samsung Electronics to secure a consistent supply of high-quality semiconductor components for its products. By fostering long-term partnerships and investing in supplier development programs, Apple enhances its supply chain resilience. These relationships not only ensure a steady flow of critical components but also enable Apple to maintain stringent quality standards, which are essential for its brand reputation and market success. As noted by Ref. [20], the ability to manage and cultivate these supplier relationships is particularly important in the semiconductor industry, where the complexity and specificity of components require a deep level of collaboration between buyers and suppliers.

For semiconductor companies, efficiency gains have been largely driven by the adoption of lean manufacturing techniques. Leading wireless technology company Qualcomm Incorporated has successfully incorporated lean concepts into its manufacturing procedures. Through an emphasis on eliminating waste, optimizing workflows, and enabling staff to find and fix inefficiencies, Qualcomm has significantly increased production

throughput while lowering costs. This lean methodology not only improves operational effectiveness but also cultivates a continuous improvement culture by enticing staff members to innovate and streamline procedures. Ref. [41] states that having a culture like this is crucial to staying competitive in a field where technology is advancing at a rapid pace. Technology adoption is another important component in semiconductor supply chain optimization. Companies such as NVIDIA Corporation have embraced innovative technologies like robots and artificial intelligence (AI) to automate industrial processes and improve decision-making capabilities. NVIDIA uses AI-powered demand forecasting models to accurately predict market trends, allowing for more informed procurement and production decisions. Furthermore, robotics-driven production lines allow NVIDIA to maintain high levels of precision and efficiency in manufacturing, hence streamlining its supply chain. The combination of these technologies not only improves operating efficiency but also NVIDIA's capacity to respond quickly to market developments, hence strengthening its competitive position in the semiconductor market [37].

Risk management is an essential component of supply chain optimization in the semiconductor industry, especially when considering the supply chain's complexity and global scale. For example, Texas Instruments Incorporated demonstrates how semiconductor companies deal with supply chain difficulties. The firm employs significant risk management strategies, including diversifying its supply base, maintaining strategic inventory buffers, and constantly monitoring geopolitical issues. According to Ref. [34], these strategies are designed to mitigate vulnerabilities and ensure business continuity, even in the face of unforeseen disruptions. By maintaining a robust risk management framework, Texas Instruments enhances its resilience and ability to navigate the uncertainties inherent in global supply chains.

For semiconductor procurement to be innovative and agile, a culture of continual improvement is necessary. Corporations that aggressively promote employee participation in process improvement efforts, such as Advanced Micro Devices (AMD), foster an environment that fosters creativity and consistently improves efficiency. This strategy not only establishes AMD as an innovative leader in the semiconductor industry but also contributes to ongoing improvements in supply chain performance. Ref. [23] highlights that AMD encourages its employees to question existing processes and embrace change, ensuring that its supply chain practices remain flexible and responsive to evolving market demands.

4.4.2 Sustainability and Ethical Sourcing in Semiconductor Procurement

Sustainability and ethical sourcing have become vital in semiconductor procurement, driven by increasing consumer demand for environmentally and socially responsible products. The importance of sustainable procurement practices in enhancing brand reputation and mitigating regulatory risks has been underscored by research, highlighting the need for semiconductor companies to integrate sustainability principles into their procurement strategies to address environmental, social, and governance (ESG) risks [59].

Environmental stewardship is an essential component of sustainable semiconductor procurement. Companies are increasingly evaluating their suppliers' environmental behavior and implementing green procurement policies to lower their carbon footprint and environmental effects. Prioritizing sustainable material sourcing, energy-efficient manufacturing methods and waste reduction activities is critical to promote resource efficiency and environmental sustainability throughout the supply chain [60]. Ethical sourcing techniques are critical to guaranteeing fair labor standards and human rights protections. Supplier codes of conduct that require strict labor standards and ethical business practices are useful in this regard. To ensure compliance with labor rules and international norms, such as the International Labour Organization (ILO) agreements, strict supplier screening processes and audit systems are in place [61].

Opportunities for cost reductions and operational improvements are provided by sustainability initiatives. It has been shown that waste reduction programs and energy-efficient manufacturing techniques increase cost savings and boost semiconductor manufacturers' profitability. Another strategic approach to cut carbon emissions and energy costs—and therefore improve business profits while lessening environmental impact—is to invest in renewable energy sources, like solar and wind power [62]. Economic sustainability is a component of sustainability that goes beyond environmental and social sustainability. An important approach is to help local communities and encourage economic development to foster economic sustainability. To generate shared value and support sustainable economic growth, semiconductor businesses participate in supplier diversity initiatives, workforce development programs, and community outreach activities [63].

Ethical sourcing practices include responsible supply chain management and transparency. Semiconductor firms use technology to track and trace the origin and sustainability of materials, ensuring that they meet ethical and environmental criteria. Supplier codes of conduct, audit programs,

and sustainability certifications are used to encourage responsible sourcing and reduce reputational concerns [64]. Collaboration and stakeholder engagement are critical for achieving sustainability and ethical sourcing objectives in semiconductor procurement. Collaboration with industry partners, government agencies, and non-governmental organizations (NGOs) is essential for creating industry standards, best practices, and sustainability frameworks that support responsible sourcing [65].

Regulatory compliance and risk management are critical in attempts to promote sustainability and ethical sourcing. Monitoring regulatory developments and industry trends is critical for ensuring compliance with environmental, labor, and social requirements. On the other hand, proactive risk management and contingency planning are critical for minimizing supply chain disruptions and managing rising sustainability concerns like climate change and resource scarcity [66]. It is essential to develop innovative strategies for overcoming challenges in sustainability and ethical sourcing, particularly in the context of evolving global regulations and technological advancements.

5. Conclusion

Supply chains play a critical role in the success of corporations, particularly in the semiconductor industry, which operates on a global scale and is integral to the production of modern technological devices. The rapid pace of technological advancement has driven significant growth and heightened competition in this sector, leading to increased specialization where certain players dominate specific areas of the supply chain. This specialization introduces both risks and opportunities, influenced by geopolitical tensions, natural disasters, and swift technological changes. This study contributes to the literature through providing a comprehensive review of the semiconductor supply chain while exploring available purchasing models and identifying factors that help shape purchasing decisions. These decisions have both immediate and long-term implications, and this review suggests strategies to build resilient purchasing models that can withstand challenges and promote innovation. It is essential to uncover emerging trends and challenges to help procurement teams take proactive measures, as well as to examine how geopolitical factors can be anticipated and managed to minimize risks. Additionally, corporate involvement in trade agreements could further enhance supply chain resilience and innovation.

5.1 Challenges and Limitations in Implementing Purchasing Models

There are several challenges that corporations are likely to face during the execution of their purchasing models in the semiconductor supply chain. The first and arguably the most common is the complexity of the supply chain networks. The supply chain is primarily influenced by a few large players in different countries, each with its area of dominance and ambitions. It is also characterized by multiple tiers of suppliers, distributors, and logistical procedures [67]. To effectively navigate this environment, one must develop reliable communication, forecasting, and coordination capabilities in collaboration with the relevant partners in the industry, which can be difficult to achieve.

The volatility in market dynamics is yet another sector where corporations are likely to face numerous challenges. The rivalry between China and the US has resulted in the development of trade policies that are likely to affect China's supply chains by significant proportions [35]. Since they are one of the largest consumers in the semiconductor industry and have numerous manufacturing corporations, there are likely to be significant price fluctuations and market uncertainty soon. Consequently, major corporations are exposed to risks that complicate the development and implementation of effective purchasing models [68]. The interdependence within global supply chains exacerbates this vulnerability, further complicating risk management strategies.

Supplier reliability and dependency are also factors that need to be addressed by some of the major players in the industry. Some corporations and countries have focused on enhancing their dominance in specific sectors of the supply chain, enabling them to have an upper hand in terms of influence on the entire supply chain. This can be dangerous for manufacturers, especially the ones that are completely reliant on a handful of suppliers capable of filling their orders at cost-effective prices [67]. In the case of natural disasters, geopolitical tensions, or any other unforeseen event, their operations can be affected significantly. It is important to diversify suppliers to insulate the corporation from such risks.

Cost pressures and margin compression are likely to occur owing to the level of competition in the industry. Corporations in the industry are under immense pressure to reduce costs as much as possible to ensure they can remain competitive. However, this contradicts strategies such as increasing investment in supplier and client relationships as well as research and development which could be advantageous to the corporation overall. Procurement and management teams are tasked with striking the balance between reducing

costs while increasing the quantity and quality of production and building a sustainable business in the sector.

The changes in technology on a day-to-day basis present opportunities and challenges to suppliers and corporations in the semiconductor industry. While digital technology can be used as a tool to analyze data and provide meaningful insights into the industry, automate operations, and increase visibility, the changes in demand for various products require increased investment in infrastructure and development capabilities to keep up with growing demands [67]. Leveraging digital solutions could prove to be a valuable tool when it comes to forecasting to reduce risk in the sector. Addressing these challenges will require management teams to adopt a comprehensive approach that integrates different models based on the corporation's supply chain.

5.2 Implications for Future Research

Exploring the complexities and challenges within the semiconductor supply chain provides numerous opportunities for future research. One key area is the dynamics between suppliers and consumers, particularly the benefits and drawbacks of investing in strong partnerships. Research has shown that aligning supplier operations with client objectives can significantly enhance the effectiveness of purchasing models [69]. Quantifying the value of these relationships and collaborations could provide valuable insights.

Sustainability and ethical sourcing are also critical areas for examination. The semiconductor industry is influenced by various geopolitical and economic factors in sourcing and manufacturing. Research could shed light on navigating these complexities to establish transparent and reliable supply chains, reducing risks and uncertainties [70]. This would allow companies to focus on the quality of their operations and products. Additionally, analyzing the origins and developments of trade tensions and regulatory changes is important, as these significantly impact supply chain management [71]. Reducing dependency on potentially hostile nations and enhancing supply chain resilience in a global context would benefit industry stakeholders.

Performance measurement and evaluation are essential for understanding the semiconductor sector's dynamics. Developing comprehensive metrics and key performance indicators for assessing purchasing models and benchmarking against industry standards could facilitate continuous corporate development [70]. This would enable companies to make informed, data-driven decisions to improve existing purchasing models and enhance performance.

Researching digital transformation and the use of technological tools in purchasing models presents

another opportunity. The implementation of artificial intelligence and analytical tools in procurement could help identify trends within corporations and markets [72]. Recognizing patterns would allow procurement teams to seize emerging opportunities and devise strategies to protect against anticipated risks in the market and supply chain.

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