OUTSOURCING TRENDS IN SEMICONDUCTOR INDUSTRY

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Submitted to the MIT-Sloan School of Management and School of Engineering in partial fulfillment of the requirements for SDM Fellows Program for the Degree of Masters in Engineering and Management

Abstract

Microelectronic devices traditionally were manufactured by companies that both designed and produced integrated chips. This process was important in 1970's and 1980's when the manufacturing processes required tweaking the design, understanding of the manufacturing processes and occasional need to redesign. As manufacturing techniques and standards evolved, companies have changed their business model and have started to outsource their manufacturing to merchant foundries. Semiconductor companies have also started to outsource the design and verification of their chips to third party design service companies and focus on core competence like research and development of new technologies and defining protocols. This trend has evolved even though the chips have become much more complex, hard to design and hard to manufacture.

This thesis studies the different players in the supply chain, how each player has evolved and the challenges companies face in making decisions regarding outsourcing internal processes. It was found that the advancements in the downstream industries such as EDA, Design Suppliers and EMS have helped fabless companies remain competitive with IDM's (Integrated Device Manufacturers). The fabless companies compete in different markets that do not need the most advanced processing technologies used by leading-edge companies.

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First and foremost, I would like to thank my parents, who instilled in me the determination to follow my passions in life.

I would like thank Professor Daniel E Whitney, my advisor, for his advice and guidance throughout the process of writing this thesis. His uncanny ability to find common ground between my interests and his made both of us engaged in this process.

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1 CHAPTER 1: THESIS OUTLINE

1.1 Introduction: Executive Summary

The semiconductor industry has been the center of attraction ever since the acceleration of the US productivity in the late 1990's.This acceleration has been due to the size of its contribution to that acceleration. The industry has been the fourth largest contributor, accounting for 0.20 of the 1.33 percentage point economy-wide production acceleration[1]. The industry enables the generation of $1200 billion in electronic system business and $500 billion in services, representing 10% of the world GDP[2]. The industry's contribution is also fueled by its relationship with Moore's law which states that *"The number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every 18 months"*.

While Moore's law can explain the productivity growth rates in chip manufacturing, it cannot on its own explain the acceleration in productivity[3]. Rather, the growth resulted from the acceleration in the number of chips shipped every year and due to the acceleration of the technology itself, developed at companies such as Intel, Samsung, and AMD. The frequency in the release of newer chips (or shortening of product life cycle) was a managerial response to changes in traditional market forces: a surge in competitive intensity, technological improvements in complementary industries and an increase in demand.[4]

Through the 1980's and 1990's, the market grew at a rapid rate with CAGR varying between 11 to 23 percent. Since mid 1990's, the CAGR has slowed down and hovers around 5 to 10 percent[5] (see figure 1). The growth in the key demand drivers such as PC's and mobiles have slowed down and the market is in a constant search for new market dominating applications.

[1] The semiconductor Industry – MGI/High tech practice new economy study, Oct 3, 2001
[2] http://en.wikipedia.org/wiki/Semiconductor_industry.

[3] The semiconductor Industry – MGI/High tech practice new economy study, Oct 3, 2001
[4] The semiconductor Industry – MGI/High tech practice new economy study, Oct 3, 2001
[5] How to respond to changes in the semiconductor value chain, Gartner Research – ID: G00126802

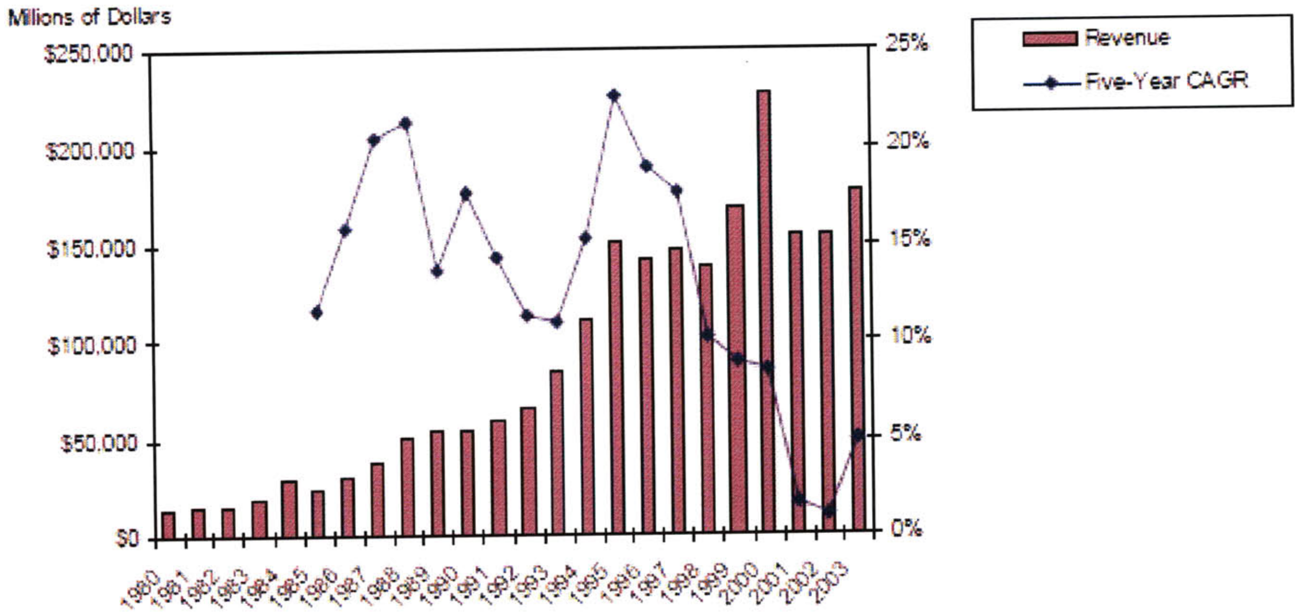


Figure 1: Five year CAGR of Semiconductor Market has slowed since the 1990's[6]

Even though the overall productivity of the industry has increased as a whole there is huge variance in the performance of individual companies. The exponential pace of Moore's law coupled with intense competition presents risks and challenges in the delivery of successful products in highly volatile markets. Among the greatest risks confronted by semiconductor companies is the high degree of uncertainty in the demand of the products and supply of key inputs. Prediction of demand is extremely difficult due to changes in technology and technological standards, uncertainty in the market acceptance of new products and changes in customer spending behavior on high technology products. If the demand is higher than expected, companies may fail to capture the additional earnings and future investment opportunities and if the demand is lower, inventory levels would increase and companies will have to lower the prices to a bare minimum to push the products into the market.

There exists a strong need for innovation in order to constantly adjust to the rapid pace of change in the market. Products that embed semiconductor devices have a short life span and prices decline rapidly. The first mover commands a high premium for his products and captures a larger chunk of the potential industrial earnings while the late movers incur huge losses and barely

[6] How to respond to changes in the semiconductor value chain, Gartner Research – ID: G00126802

breakeven as semiconductor products tend to commoditize early. The DRAM (Dynamic Random Access Memory) product is an excellent example. The DRAM price was falling rapidly and in late 2007 Micron Technology stopped selling DRAM's as their prices in the market were nearing the cost of production.

The semiconductor industry has undergone a transformation in which processes such design and manufacturing requiring high capital expenditures are now distributed across companies at different stages of the value chain. Companies have adopted various outsourcing strategies to reduce costs and risks associated with them. Companies have eliminated the need to own an internal fabrication plant by outsourcing their manufacturing to foundries such as TSMC (Taiwan Semiconductor Manufacturing Corporation) and UMC (Universal Manufacturing Corporation). Also the demand and supply changes in the semiconductor supply chain have led to emergence of several new players such as third party design suppliers, EDA (Electronic Design Automation) and EMS (Electronic Manufacturing Services) companies.

This thesis describes the role played by each player in the supply chain, the industry transformation and the risks and challenges of making outsourcing decisions rationally. It compares companies making different products, targeting different market segments and making make-buy decisions resulting in very different relationships along the company's value chain. The decisions are not limited to skills related to the product but include choices related to financing, availability of skilled labor, diversification of risks and manufacturing issues.

1.2 Motivation

The author's motivation to work on this topic stems from his background in semiconductor industry and willingness to broaden his knowledge about the trends, challenges and risks considering the technological advancements in design and manufacturing processes.

The following engineering and management concepts are used in this thesis.

- Core competencies
- Product design and development
- System Engineering

- Risk Management
- Corporate strategy
- Real Options

Once a fully integrated vertical industry - in which companies like IBM, Hewlett Packard and Sony performed all value chain activities ranging from design to marketing and sales – the industry today has transformed due to widespread outsourcing of activities and adoption of fabless business model. With the emergence of fabless business model, companies have altered the way they design and manufacture their products. The fabless ecosystem consists of companies that carve out niches to capture value and offer specialized services to capture it. The goal of the thesis is to understand the factors that changed the industry landscape and the capabilities that downstream companies have developed to aid fabless companies to compete against the Integrated Device Manufacturers.

The challenges faced by semiconductor companies today arise from two conflicts. First, wafer manufacturing factories ("fabs") are becoming prohibitively expensive, and it is economical only to manufacture high volume products that get to market fast and make a profit before they become commodities. Second, the best way to coordinate the design and manufacturing of leading-edge semiconductors is for companies to make their own designs in their own fabs. To get the most economical use out of expensive fabs, it is necessary to remove design errors rapidly and increase the yield of good chips. This, too, requires integration of design and manufacturing. Long iterations between design and manufacturing lengthen the time to market, risking loss of market share and profits. New entrants into this industry usually cannot afford their own fabs and must find a different way to get their chips made. Whatever way they choose, they must coordinate design and manufacturing, remove errors quickly, get the yield up, and get to market fast. The new ecosystem of the industry, described in this thesis, has arisen to meet these challenges

The thesis is structured as follows

Chapter 2 provides a brief introduction of the supply chain of the semiconductor industry, the factors affecting the supply chain and the key value propositions that drive this industry

Chapter 3 details the industry evolution and the history of process improvements that led to the emergence of new players in the supply chain

Chapter 4 introduces the trend of companies outsourcing design of integrated chips, the drivers and challenges associated with it and the design service business models.

Chapter 5 explains the changes in the semiconductor manufacturing industry, the factors driving those changes and the capabilities that downstream companies have developed to reduce complexity involved in manufacturing for companies that have adopted fabless model

Chapter 6 provides an overview of the key nuggets learned from the analysis of outsourcing trends in semiconductor industry and capabilities that fabless companies should adopt to effectively respond to industry dynamics and stay ahead of the competition.

1.3 Background and Literature Review

In order to understand the research and subsequent analysis and recommendations, it is important to understand the prior work done in this field. The following papers were reviewed to gain the knowledge required to apply the concepts used in similar industries, such as automotive industry, to semiconductors.

1.3.1 Charles Fine and Daniel E. Whitney (1996). "Is the make-buy decision process a core competence?"

Fine and Whitney examined the complexity of products and concluded that no single company has all the necessary knowledge about their product or the required processes to completely design and manufacture them in-house. They found that companies are dependent upon their upstream and downstream players in the value chain. They compared the make/buy patterns of Japanese and US car manufacturing companies which resulted in very different patterns of interdependencies along the company's value chain. Figure 2 illustrates the supply chain patterns in the automotive industry. The US companies manufacturing equipment and much of the softwares are purchased from other companies and almost exactly opposite behavior is exhibited by Japanese companies.

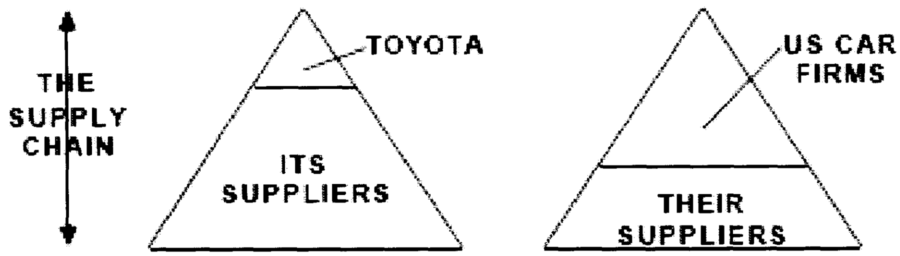


Figure 2: Lean Paradigm expressed as a partition of Triangle[7]

Figure 3 compares the make-buy behavior of US and Japanese companies with respect to product and infrastructure components.

	JAPANESE COMPANY "YOU LEARN BY TRYING, NOT BY BUYING"	US COMPANY "OUR BUSINESS IS CARS, NOT ROBOTS"
PRODUCT COMPONENT OR SYSTEM	BUY	MAKE
INFRASTRUCTURE COMPONENT OR SYSTEM	MAKE	BUY

Figure 3: Make-Buy matrix for US and Japanese car manufacturers[8]

Their argument of outsourcing in car manufacturing industry is classified into two categories of dependency: Dependency for capacity and dependency for knowledge. In the former case, the company has the knowledge to make the item but for reasons of money, time or management attention decide to outsource the task to suppliers. In the latter case, the company lacks the skill to make it and thus outsources to an expert supplier to fill the gap. Outsourcing is facilitated by the degree to which the architecture is modular. Table 1 shows the summary of their conclusions.

[7] Is the make-buy decision process a core competence by Charles H. Fine and Daniel E.Whitney

[8] Is the make-buy decision process a core competence by Charles H. Fine and Daniel E.Whitney

They also showed that the structure of the product and that of the industry can be quite similar: either integral/vertical or modular/horizontal. More importantly, these configurations appear to be unstable for a variety of related technical and economic reasons and have been found in several industries to cycle from one form to another.[9]

MATRIX OF DEPENDENCY AND OUTSOURCING

	DEPENDENT FOR KNOWLEDGE	DEPENDENT FOR CAPACITY
OUTSOURCED ITEM IS DECOMPOSABLE	**A POTENTIAL OUTSOURCING TRAP** YOUR PARTNERS COULD SUPPLANT YOU. THEY HAVE AS MUCH OR MORE KNOWLEDGE AND CAN OBTAIN THE SAME ELEMENTS YOU CAN.	**BEST OUTSOURCING OPPORTUNITY** YOU UNDERSTAND IT, YOU CAN PLUG IT INTO YOUR PROCESS OR PRODUCT, AND IT PROBABLY CAN BE OBTAINED FROM SEVERAL SOURCES. IT PROBABLY DOES NOT REPRESENT COMPETITIVE ADVANTAGE IN AND OF ITSELF. BUYING IT MEANS YOU SAVE ATTENTION TO PUT INTO AREAS WHERE YOU HAVE COMPETITIVE ADVANTAGE, SUCH AS INTEGRATING OTHER THINGS
OUTSOURCED ITEM IS INTEGRAL	**WORST OUTSOURCING SITUATION** YOU DON'T UNDERSTAND WHAT YOU ARE BUYING OR HOW TO INTEGRATE IT. THE RESULT COULD BE FAILURE SINCE YOU WILL SPEND SO MUCH TIME ON REWORK OR RETHINKING.	**CAN LIVE WITH OUTSOURCING** YOU KNOW HOW TO INTEGRATE THE ITEM SO YOU MAY RETAIN COMPETITIVE ADVANTAGE EVEN IF OTHERS HAVE ACCESS TO THE SAME ITEM.

Table 1: Matrix of Dependency and Decomposition[10]

[9] Is the make-buy decision process a core competence by Charles H. Fine and Daniel E.Whitney
[10] Is the make-buy decision process a core competence by Charles H. Fine and Daniel E.Whitney

1.3.2 Physical Limits to Modularity by Daniel Whitney (1996):

In this paper, Whitney discusses the distinction between typical mechanical and VLSI systems that has gained new relevance as attention has turned into developing a new theory of engineering systems. He argues that designers of mechanical systems do not have the degrees of freedom to define modules as do designers of VLSI systems. A more modular architecture permits modules to be identified as the differentiators that will be customized for different purchasers[11]. Modular architectures support outsourcing allowing companies to share risk or gain access to knowledge and capabilities that are not available in-house. Table 2 shows the summary of differences between VLSI and mechanical Systems. This paper highlights the importance of a modular design and the challenges involved in outsourcing a modular architecture- which can be applied for outsourcing semiconductor processes.

[11] Physical Limits of Modularity, Daniel E Whitney, 2006

ISSUE	VLSI	Mechanical Systems
Component Design and Verification	Model-driven single function design based on single function components; design based on rules once huge effort to verify single elements is done; few component types needed	Multi-function design with weak or single-function models; components verified individually, repeatedly, exhaustively; many component types needed
Component Behavior	Is the same in systems as in isolation; dominated by logic, described by mathematics; design errors do not destroy the system	Is different in systems and in isolation; dominated by power, approximated by mathematics, subject to system- and life-threatening side effects
System Design and Verification	Follows rules of logic in subsystems, follows those rules up to a point in systems; logical implementation of main functions can be proven correct; system design is separable from component design; simulations cover all significant behaviors; main system functions are accomplished by standard elements; building block approach can be exploited and probably is unavoidable; complete verification of all functions is impossible	Logic captures a tiny fraction of behavior; system design is inseparable from component design; main function design cannot be proven correct; large design effort is devoted to side effects; component behavior changes when hooked into systems; building block design approach is unavailable, wasteful; complete verification of avoidance of side effects is impossible
System Behavior	Described by logical union of component behaviors; main function dominates	No top level description exists; union of component behaviors irrelevant; off-nominal behaviors may dominate

Table 2: Summary of Differences between VLSI and Mechanical Systems[12].

1.3.3 Modeling Strategic semiconductor assembly outsourcing decisions based on empirical settings- Jei-Zheng Wu and Chen-Fu Chien (2008)

Wu and Chien have developed a decision framework in which preference over vendors at strategic level and order allocations at operational level can be integrated. Most chip makers that focus on wafer manufacturing outsource assembly to reduce operational costs, diversify the risks among the vendors and to enhance the capital effectiveness of investments. This literature has been abundant on proposing strategies for outsourcing semiconductor manufacturing and

[12] Physical Limits of Modularity, Daniel E Whitney, 2006

assembly processes and concludes that a 'cost only' model of outsourcing can lead to local optimization and long term difficulties.

1.3.4 Global Product Development in Semiconductor industry Intel: Tick-Tock product development cadence by Cheolmin Park, 2008

Park investigates the changes in the semiconductor product development methodology at Intel for the last 10 years due to the challenges faced by changing customer demands, competitor's response, manufacturing challenges and how they overcame from the short period performance dip and implemented new development platform, Tick-tock cadence. The thesis suggests introducing the system department to lead the Intel's future product development strategy performed in the globally dispersed development sites (GPD)[13]. It helped to understand the various processes involved in a semiconductor product development process and the challenges involved in managing a globally dispersed development team.

1.3.5 Definition of Modularity

Modularity is defined as a property of a system that describes how closely 'form' maps to 'function'. Ulrich and Eppinger describe a modular architecture as one in which each physical element of the system implements a specific set of functional elements and has well-defined interactions with other physical elements[14].

Baldwin and Clark define modularity in terms of interdependence within and independence among modules plus management of complexity by information hiding within each module.[15] Thus a design can be visualized as an aggregation of modules and connections that can be designed independently by describing a set of design rules.

Baldwin and Clark, in their book Design Rules, have described how modularity has affected the computer industry. The effect of modularization on this industry has been so positive that "today, this highly evolved, decentralized social framework allows tens of thousands of computer designers to work on complex, interrelated systems in a decentralized, yet highly coordinated

[13] Global Product Development in Semiconductor industry Intel: Tick-Tock product development cadence by Cheolmin Park, 2008
[14] Ulrich, Karl T. and Steven D. Eppinger, Product Design and Development, 2nd Ed, McGraw-Hill, 2000.
[15] Design Rules, The power of Modularity – book written by Carliss Y.Baldwin and Kim B.Clark.

way"[16]. This thesis identifies the extent of modularity involved in a semiconductor product development process and how individual players have emerged to expand the network to make the process more decentralized.

Suh's concept of Axiomatic design argues more in the favor of modularity. The process involves decomposition of customer needs to functional requirements to design requirements and then to process variables. An Axiomatic design is based upon two basic axioms

- All the functional requirements must be independent of each other
- Information content of the design must be minimized and is the logarithm of the inverse of the probability of delivering the functional requirements[17]

Decoupled

$$\begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & X & X & 0 \\ X & 0 & X & X \end{bmatrix}$$

$$\begin{Bmatrix} FR11 \\ FR21 \\ FR22 \\ FR31 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP11 \\ DP21 \\ DP22 \\ DP31 \end{Bmatrix}$$

Uncoupled

$$\begin{bmatrix} X & X & 0 & X \\ 0 & X & 0 & X \\ X & 0 & X & 0 \\ 0 & X & X & X \end{bmatrix}$$

Coupled

Figure 4: Modularity in Axiomatic Design[18]

Figure 4 shows how functional requirements can be mapped to design parameters in matrix form. The figure shows that matrix must be triangular in order for the design to be decoupled and diagonal to be completely uncoupled.

[16] Baldwin, Carliss Y. and Kim B. Clark, Design Rules: The Power of Modularity, Volume 1, The MIT Press, 2000.
[17] Suh, Nam P., The Principles of Design, Oxford University Press, 1990.
[18] Power Management as a system-level inhibitor of modularity in the mobile computer industry, Samuel K. Weinstein, June 2004

2 CHAPTER 2: SUPPLY CHAIN IN SEMICONDUCTOR INDUSTRY

2.1 Introduction

Michael Porter in his book "Competitive Advantage in 1985" has described that in a classic value chain the goal of every player is to add more value for the customer than the cost of carrying out the service. The ability of each player to add or capture value depends ultimately on a cost advantage, on product or technology differentiation, or on the ability to reconfigure the value chain[19]. This chapter provides a current view of the supply chain in the semiconductor industry, the supply and demand side factors affecting the supply chain and the activities that can be outsourced in a semiconductor product development process

2.2 Overview of Semiconductor Value Chain

The value chain of any industry consists of the following components: R&D, purchasing, manufacturing, distribution and end customers. The semiconductor value chain has undergone dramatic and rapid changes over the last three decades and consists of the following players as shown in Figure 5. The chain includes multiple design vendors, sub-suppliers, contractors, internal and external manufacturing service providers, distributors and end customers. The structure of the value chain has changed due to supply and demand changes and due to the degree of vertical integration that has existed to maximize the profit at a given point in time. As the number of players in the value chain increases, the margin gets squeezed and the value created with electronic applications will be distributed among a greater number of intermediaries.

The semiconductor value chain is extremely complex and when the market experiences erratic changes in demand, the upstream players get affected the most. Because of the number of significant shifts in how industry does business, players in the value chain have regrouped to build and strengthen capabilities that enable them to work efficiently and maximize their earnings potential. The supply chain is more hierarchical as the end-customers cannot buy directly from the OEM's and have to buy from distributors/retail stores.

[19] How to respond to changes in the Semiconductor Value Chain, Gartner Research, ID number – G00126802

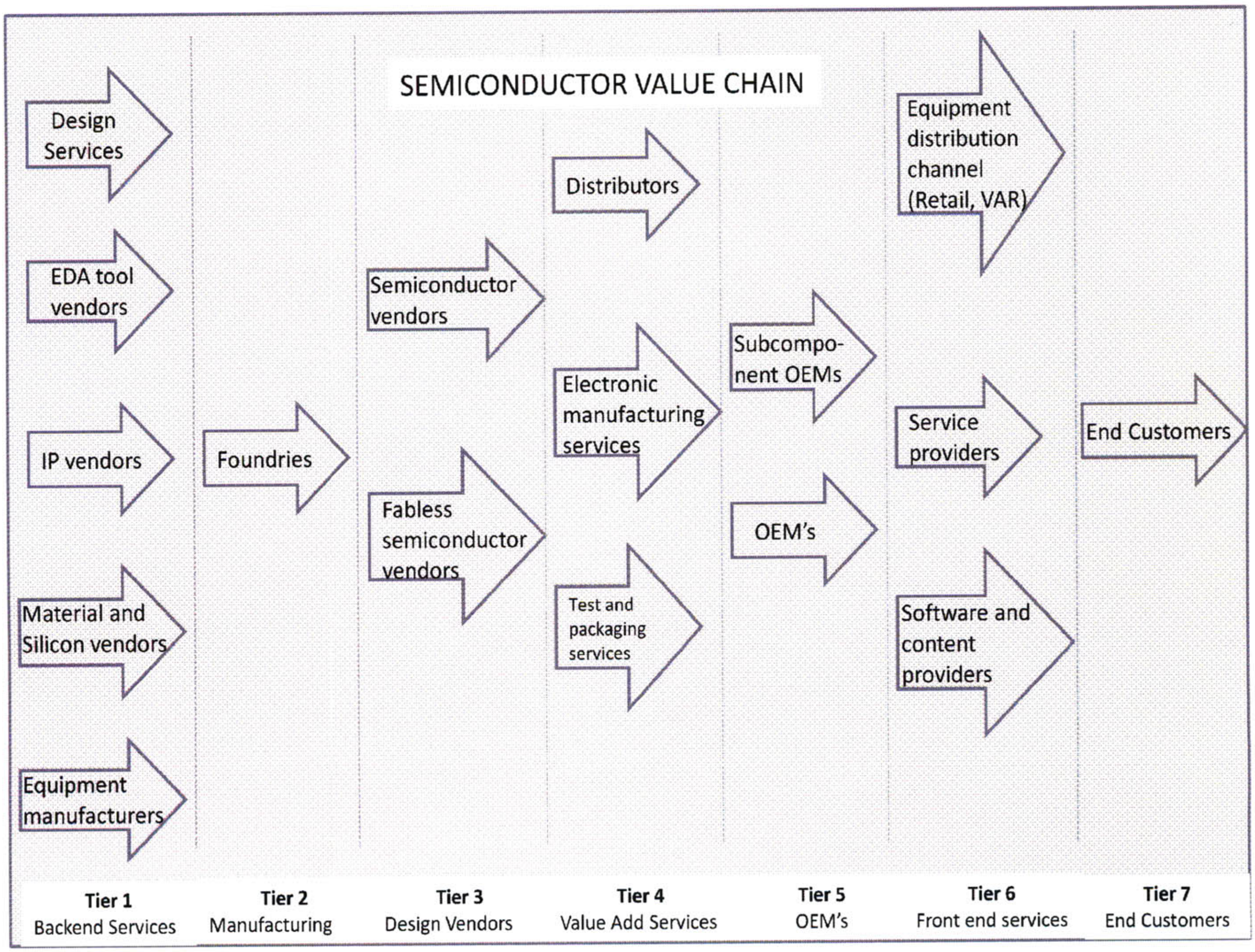
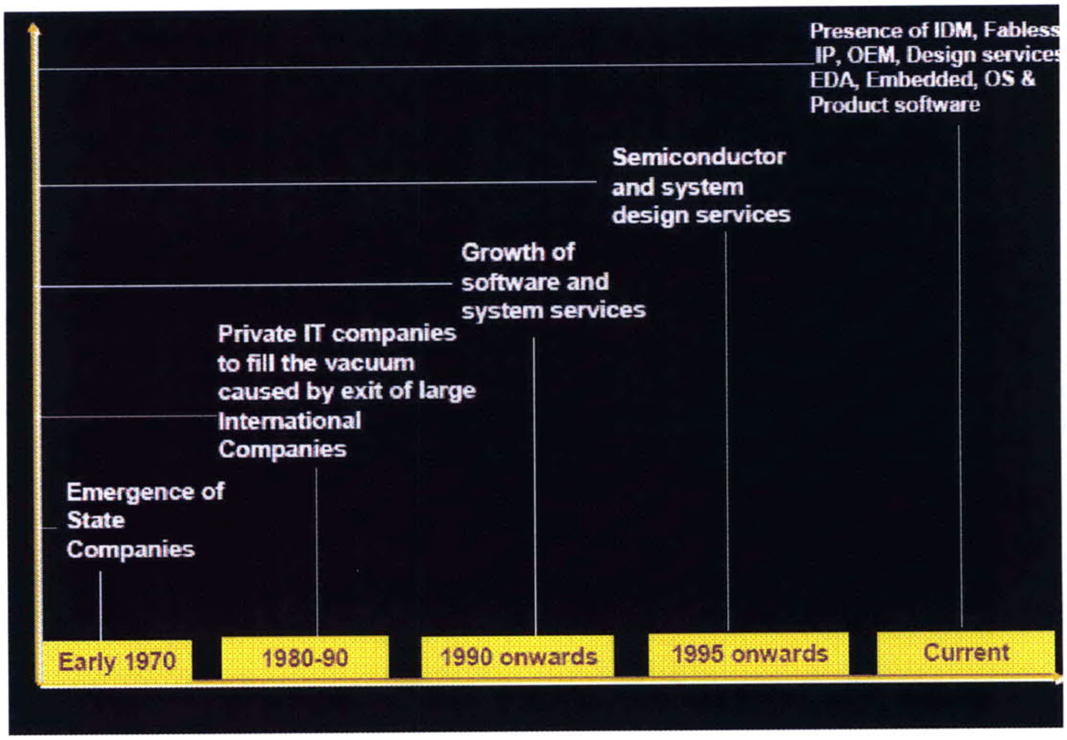


Figure 5: Semiconductor Value Chain

a) **Design Services (Tier 1)**: These are companies that do not make semiconductor devices but provide design and verification services to companies that outsource to them. The growth of the supply base started in 1990's with many cost advantages and price competition associated with them. i.e during the time when companies were going fabless. Although this trend has not yet reached the level of manufacturing outsourcing, design outsourcing has been on the rise and the number of designs outsourced every year is increasing. Figure 6 shows the emergence of design service companies.



* State companies- Companies with no international presence

Figure 6 – Emergence of Design Service Providers[20]

Most of the large semiconductor companies approach third party design services companies when they lack the resources and expertise required to design chips. Other companies opt for the service when the time to market is very short. Typical design service project begins with requirement analysis followed by the architectural representation of the chip, logic design involving gate level specification, layout specification and finally, tape-out for fabrication.

The design services market is segmented based on product categories. The design service suppliers have the necessary talent and resources to design the following products.

- ASIC (Application Specific Integration Circuits)
- ASSP (Application Specific Standard Product)
- Structured ASIC
- FPGA (Field programmable Gate Arrays)
- Analog and mixed signal design
- RF (Radio Frequency) design

[20] VLSI Design services market by Vasudevan, Wipro Technologies

b) EDA tool vendors (Tier 1)

These are companies that supply the global electronics market with software for designing and producing electronic systems ranging from printed circuit boards to integrated circuits[21]. Before the advent of these tools, integrated circuits were designed by hand and were manually laid out. These companies help semiconductor companies address the key challenges the designers and manufacturers are facing today and also help give a competitive edge in bringing their products to market quickly. The design service companies and the IDM manufacturers license software from EDA companies.

c) IP vendors (Tier 1)

These are companies that license reusable units of logic, cell or modules to semiconductor design houses that use them as building blocks within ASIC chip designs or FPGA logic designs. These companies require a large amount of R&D investment but do not have to pay the costs associated with manufacturing. It is an attractive alternative for big chip makers to buy parts of the design and save time and money on designing them.

d) Material and Silicon Vendors (Tier 1)

These are companies that provide silicon wafers to fabrication units, which are then etched to produce chips. A typical wafer is made out of extremely pure silicon that is grown into mono-crystalline cylindrical ingots up to 300mm in diameter using Czochralski process[22]. The ingots are then sliced into wafers of 0.75mm thick and polished to get a flat surface. Managing the supply for silicon wafers required for foundries is a challenging task.

e) **Equipment Manufacturers (Tier 1)**

These are companies that create and commercialize nano-manufacturing technology used in the production of semiconductor chips, LCD display, glass and solar (thin-film and crystalline) manufacturing industries[23].

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[21] http://en.wikipedia.org/wiki/Electronic_design_automation
[22] http://en.wikipedia.org/wiki/Semiconductor_device_fabrication

[23] http://en.wikipedia.org/wiki/Applied_Materials

f) Foundries (Tier 2)

These are fabrication units that manufacture integrated chips. They employ a multi-step sequence of photographic and chemical processing steps during which electronic circuits are gradually created on a wafer made of pure semiconductor material[24].

g) IC vendor (Tier 3)

These are companies that design, manufacture the chips in-house and sell them in the market. The term Integrated Device Manufacturers is often used to differentiate companies that handle manufacturing in house and companies that outsource the manufacturing (Fabless semiconductor design vendors).

h) Electronic Manufacturing services (Tier 4)

These are companies that supply process control and yield management solutions for semiconductor manufacturing industries. The software products are designed to help IC manufacturers manage yield throughout the fabrication process – from research and development to final yield analysis. Yield management is directly connected to the bottom line of the company.

i) Test and packaging services (Tier 4)

These are companies that test and package the chips from the manufacturing units. Testing and packaging services are generally outsourced to companies that provide leading-edge package solutions for latest generation applications. As integrated circuits increase in speed and complexity, the right semiconductor packaging becomes critical to ensure optimal system performance.[25]

j) OEM's (Tier 5)

These are companies that purchase a component made by another company for use in the purchasing company's products. For instance if company 'A inc' purchases optical drives

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[24] http://en.wikipedia.org/wiki/Semiconductor_device_fabrication

[25] http://www.amkor.com/go/about-us

from company B that will be used in A Inc computers, then company A is the OEM[26]. These companies are also called as VARs (Value Added Resellers). There are multiple tiers of OEM's with the top tier OEM's selling to the end customers and the lower tiers selling to the higher tiers.

k) Software and content providers (Tier 6)

These are companies that supply front end applications that run on the devices. The applications include operating system and supporting packages.

l) Service providers (Tier 6)

These are companies that provide computer based services to customers over a network. The software used in an ASP model is also called as On-demand software or software as a service.

Table 3 shows the number of players and the main players in each category.

Supply Chain player	Number of Companies	Main Suppliers/Customers
Design Services	10+	Wipro Technologies, Sasken, Tata Elixi
Design Tool Vendors	10+	Synopsys, Cadence Design Systems, Mentor Graphics
IP Vendors	10+	ARM, MIPS Technologies, ARC international
Material Vendors	5+	MEMC Electronic Materials, Wacker-Siltronic Corporation, DC Chemical
Equipment Vendors	10+	Applied Materials, ASML, Canon, ADE Corporation
Foundries	10+	TSMC, UMC
Semiconductor IDM's	10+	Intel, Samsung, Texas Instruments, Qualcomm
Fabless Semiconductor Companies	10+	Nvidia, Sandisk, AMD, Altera
Manufacturing and Design Services	10+	Foxconn, Flextronics, Quanta Computer, Compal Electronics
Test and Packaging Services	Many small companies	Amkor technology
Electronic Manufacturing Services	< 5	KLA Tencor, PDF solutions

Table 3 : Number of Players in each Category

[26] http://en.wikipedia.org/wiki/Original_equipment_manufacturer

2.3 Business Models and Partnerships

Due to the number of significant shifts in how semiconductor industry does business, players in the value chain have changed business models and formed partnerships with companies with complementary assets to succeed. High-tech businesses' performance depends on cooperation between the various niche players of the ecosystem. Significant of them is the partnership between Nokia and Texas Instruments (TI), where Nokia is the handset manufacturer and TI is the semiconductor supplier for those handsets. The partnership between these two firms is mutually beneficial.

Though partnerships have proven successful there have been events where one single player tried to create value and captured the majority of the value ecosystem. The role of Qualcomm in commercialization of CDMA (Code Division Multiple Access) technology is a good example. Qualcomm monopolized the CDMA technology through plethora of patents and aggressive licensing terms. This launched Qualcomm's growth but it also led the demise of CDMA technology questioning the sustainability of their growth curve. Lead user markets have been greatly influential in defining the Business models and are also driving the innovation in this domain. Ex: The innovation of TD-SCDMA (Time Division Synchronous Code Division Multiple Access) by Chinese Telecom, Datang and Siemens.

2.4 Intellectual Property

Intellectual property can provide rich royalties for the patent owners in parts of the world where patent laws are strictly enforced. Qualcomm, inventor of CDMA using spread spectrum, command significant royalties within the mobile communications industry and ARM Inc is a major success story in capturing value through intellectual property in the microelectronic industry. However, there is research to show that, "with few exceptions, real world value of patent protection is not very useful either for excluding imitator or for capturing loyalties in most industries"[27]. In developed countries, IP has provided companies with greater protection and exclusivity to benefit from their research.

[27] Von Hippel, E, "Democratizing Innovation", 2005, MIT press, p 84.

2.5 Power of Suppliers and Buyers in the Semiconductor Industry

The suppliers to the big semiconductor firms have very little power. Many firms have hundreds of suppliers and they diffuse the risk over many companies allowing the chip giants to keep the bargaining power of any one supplier to a minimum. However, since production and maintaining foundries are becoming expensive many small chip companies are dependent upon a handful of large foundries. Semiconductor manufacturing is a capital intensive and a low margin business – huge barrier to entry. As a result, the merchant foundries enjoy high bargaining power for supplying cutting-edge equipment and production skills.

2.6 Factors Affecting the Supply Chain

As the industry matures and consolidates, understanding the factors that caused the changes in the supply chain and profit distribution among the players becomes important. The industry participants deal with an increasingly complex group of stakeholders and have adopted new business models involving outsourcing operations to strengthen new downstream competencies, closer to end customers. The major factors affecting the shape of the industry can be highlighted by considering downstream (supply) and upstream (demand) changes in the value chain.

2.6.1 Demand Changes

The overall growth of the total available market has slowed since 1998 and the 5-year industry CAGR hovers around 5% to 10%. [28]The growth of the key applications that were driving the industry such as PC's and Cellular phones has slowed and the industry is constantly looking for new applications that can dominate the next generation market. None have emerged so far and the industry is getting driven by a large number of low volume applications. The integrated device manufacturers are finding such low volume applications difficult to manage as their fabrication units are not utilized to their capacity and they find difficult to support the design and manufacturing costs.

In addition to that, the boundaries between application categories are disappearing and applications are becoming commoditized early, shifting the value and power from hardware to

[28] How to Respond to Changes in the Semiconductor Value Chain, Gartner Research, ID Number – G00126802

service and content providers. As a result, the semiconductor companies must anticipate the needs and must expand their business to a new group of clients far beyond the original equipment manufacturers (OEM).

2.6.2 Supply Changes

Given the amount of capital required for semiconductor manufacturing and related operations, the companies have considered various business models to sustain in this industry. About 13% of the total available market is now captured by the fabless semiconductor vendors and it is likely to grow in the future[29]. Financial constraints and maturing manufacturing processes are driving companies to adopt fabless model and many companies that had in-house manufacturing are spinning out or forming alliances with other IDM's. The recent activity proving this phenomenon include AMD, that sold their fabs to Advanced Technology investment company of Abu Dhabi to create an independent semiconductor manufacturing company called "The Foundry Company". In addition to servicing the needs of AMD, the new company is also expecting to attract more customers to utilize their capacity. This phenomenon has inevitably shifted the power to foundries and the fabless semiconductor vendors would have to fight among themselves to get priority status to foundries. This model requires companies to share their IP with the foundries and increase the risk of technology leakage.

As industry costs are increasing and companies are outsourcing their manufacturing, the burden of keeping abreast with the process and material R&D has fallen back along the value chain to equipment makers and material manufacturers. For these companies, the lead time for product development is long and the return on investment is uncertain. If a technology that a major semiconductor vendor is driving fails to achieve large scale adoption, the investment in the R&D will not produce a positive return. Thus increasing costs would facilitate further industry consolidation and drive technology commoditization as the equipment makers and material manufacturers demand security of a sure bet in the form of 'super IDMs' or powerful alliance of guaranteed clients.

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[29] How to Respond to Changes in the Semiconductor Value Chain, Gartner Research, ID Number – G00126802

2.7 Key Value Propositions that drive the industry

The key value proposition that drives the industry is in the order of magnitude improvements in higher speed, lower power consumption and lower silicon area. To implement these improvements the industry is constantly in search of new technologies and new materials. The key value propositions can be experienced by the end-use in terms of:

- **Power Efficiency** is driven by the need for greater mobility, since higher the power efficiency higher is the battery life. Consequently, today's designers require implementation of a technology which supports multiple low power modes, regardless of whether the device's active power is on or it is in standby mode.

- **Throughput** (e.g., power per Mbit of data) also plays a critical role here because even if a protocol's active power is high, it may ultimately exhibit the lowest total power energy consumption, and therefore provide the best power efficiency, if it transfers data extremely fast.

- **Functionality**: Convergence of functions such as music, GPS and internet browsing with traditional phone functions is clearly evident. Even traditional devices such as laptops have started to overlap with multi-functional phones through introduction of “Ultra-mobile PC”.

- **Compactness**: In general, the size of the device is a powerful driver of adoption among consumers. Although prosumers (portmanteau for Professional Consumers) focus more on functionality, consumers have migrated to more compact sizes over time.

- **Portability:** Shape, weight, dimensions and other ergonomic features drive portability.

- **Greener Products:** Order of magnitude reduction in power consumption leads to greener products that have significant market appeal.

Figure 7 shows the evolution of the key propositions in electronic industry.

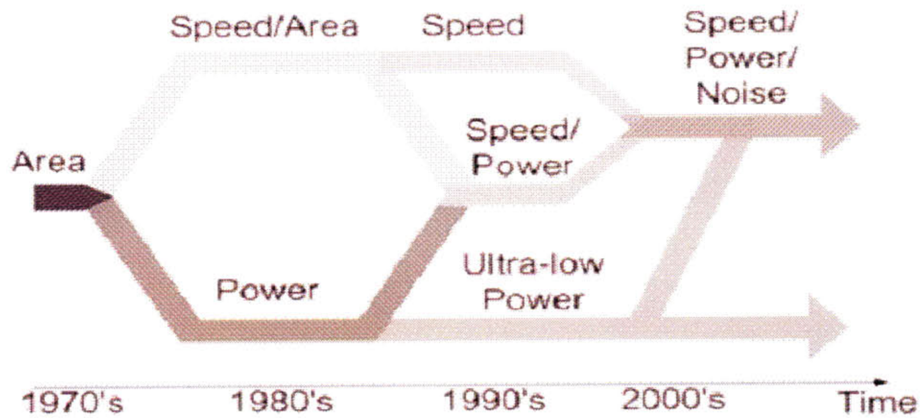

Figure 7: Evolution of Key Propositions in Electronic Industry

2.8 Semiconductor Design Process

Figure 8 shows the requirement analysis and the engineering processes and loops for a memory card product development project. The information regarding the tasks and the iterations in the product development process was gathered by conducting interviews of my co-workers who work for a leading fabless company based in California that designs and manufactures flash memory card products.

The requirement analysis is a sequential process and consists of the following steps.

***Process inputs*:** This process involves the assessment of the memory industry, gathering the customer needs and writing specification for the product. The industry analysis involves reviewing the economic, political and market factors that influence the way the industry develops. Major factors taken into consideration include competition, supplier and buyer power, substitutes and the likelihood of new entrants in the market.

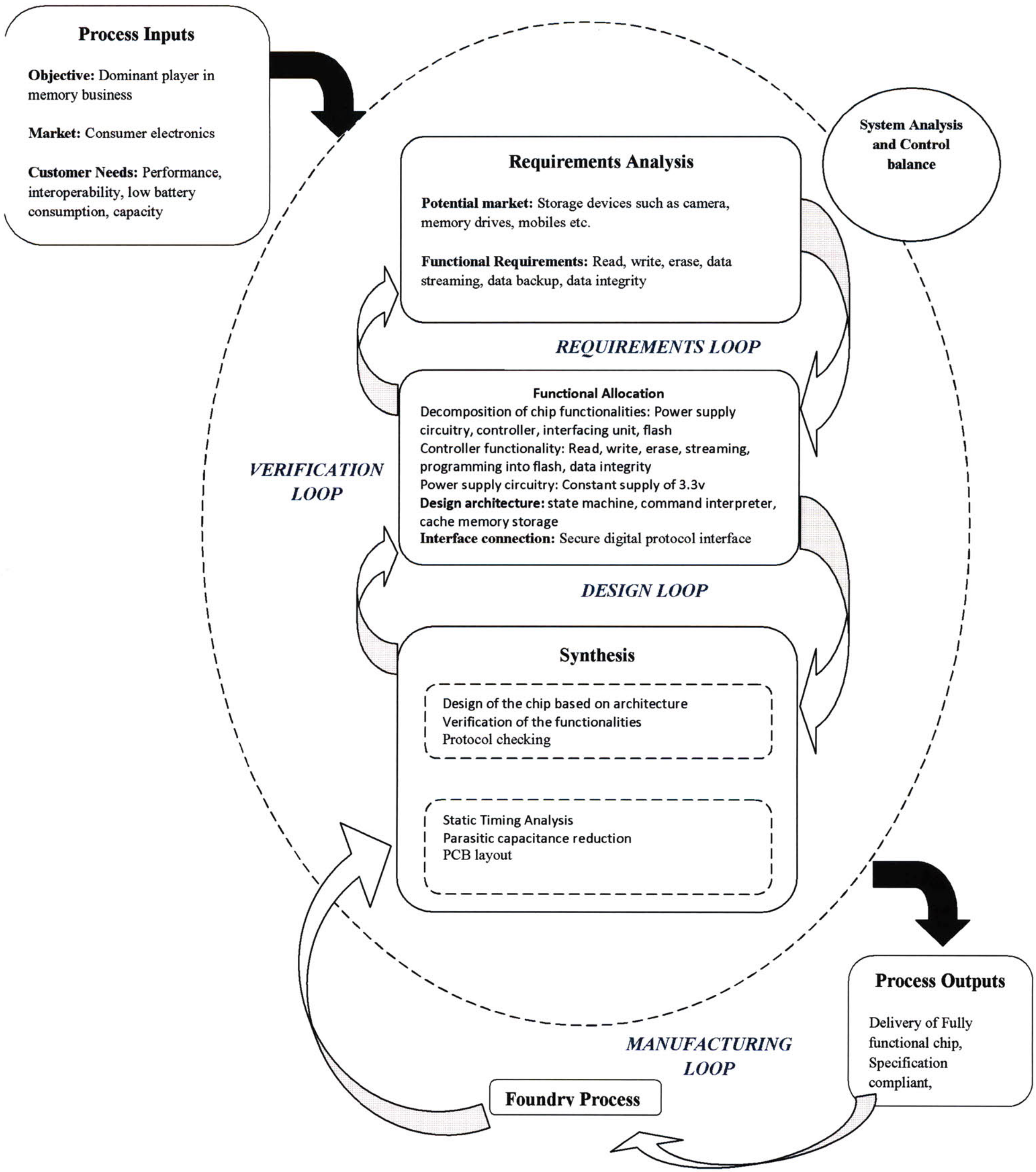

Figure 8 : Semiconductor Design Process – Requirement Analysis and Engineering Process

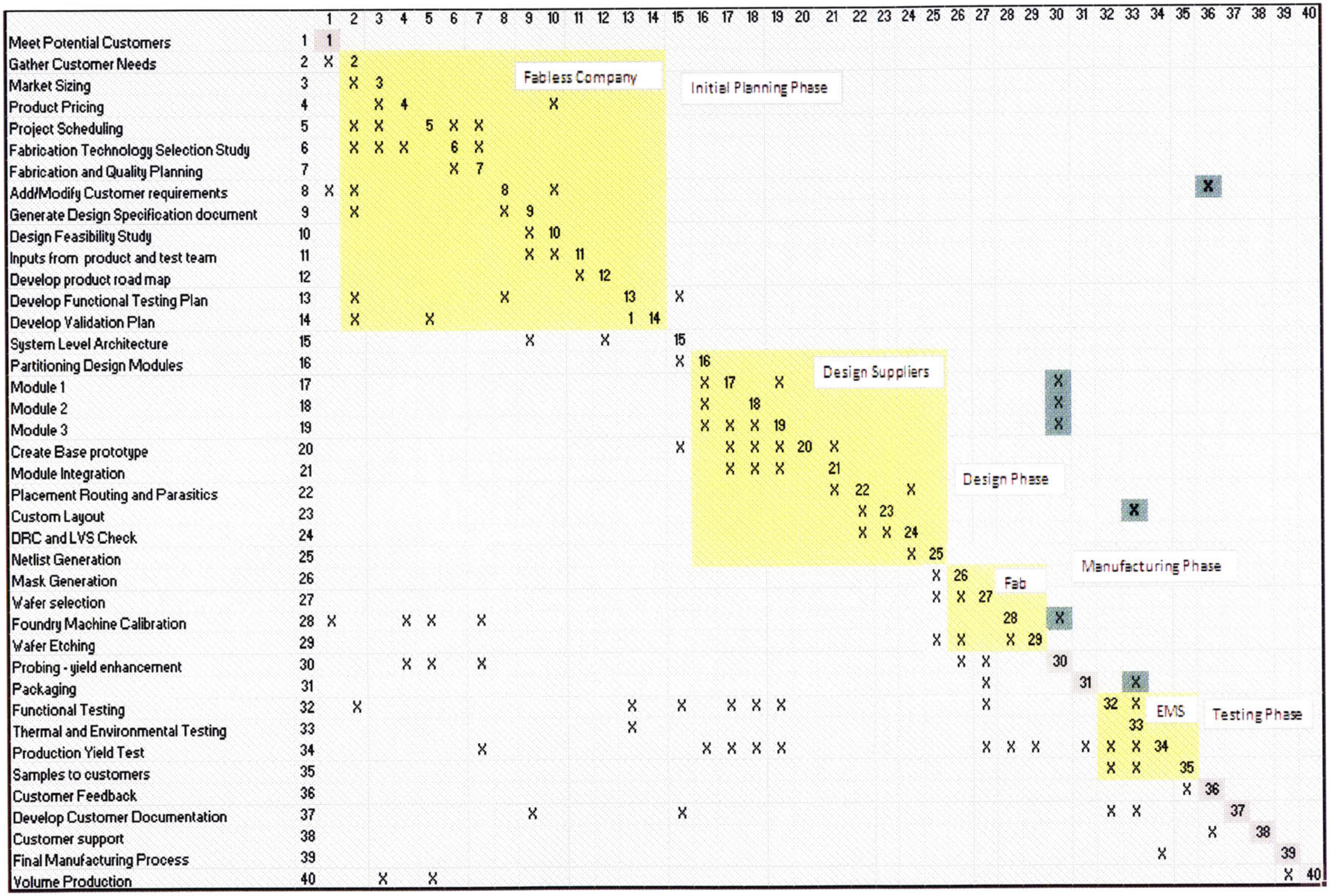

Figure 9 : Design Structure Matrix for a Semiconductor Product Development Process

Requirement analysis: This process includes identification of potential markets for the product, functional requirements, performance and constraint requirements. It is critical to the success of a product development project. The requirements gathered are actionable, measurable, testable, related to identified business needs or opportunities, and defined to a level of detail sufficient for system design[30].

***Functional Allocation*:** This process involves the decomposition of functionalities, design architecture layout and interface specification. Functionalities for a typical memory product include read, write and erase features.

Synthesis: This process involves the design and verification of the product based on the design specifications.

Foundry Process: This process involves sending the design to the foundry for manufacturing.

Requirement loop makes sure that all the customer needs are transformed into functional requirements of the product. This includes constant involvement of the end-customers for gathering feedback through surveys or by forming focus groups.

Design loop makes sure that all the functional requirements in the specification are incorporated in the design.

Verification loop takes care of verifying and validating the product. Verification is the internal testing process of determining compliance with the specifications while validation confirms the needs of external customer or user of the product.

Manufacturing loop makes sure that the chip does not have manufacturing defects and if any layout changes are required to mitigate the risk during mass production.

Figure 9 shows the design structure matrix (DSM) that lists all constituent sub processes and the corresponding information exchange and dependency patterns. DSM is a tool that can be used to perform analysis and management of complex systems[31]. It can be used to manage the effects of change and enables the user to model, visualize and dependencies among the tasks in a complex

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[30] http://en.wikipedia.org/wiki/Requirements_analysis

[31] http://www.dsmweb.org/

system. For example, if there is a problem with leakage capacitance, it is possible to quickly identify all the processes, which are dependent on that, reducing the risk of spending time on tasks that are not directly connected to it.

DSM in figure 9 was constructed by listing all the activities gathered through interviews on X and Y axis in the same order. The dependencies between the tasks are marked using symbol ‘x’. The ‘x’’s above the diagonal of the matrix are iterations and the ‘x’’s marked in green are unplanned or unanticipated iterations. A manual partitioning of the DSM results in the identification of tasks that are highly coupled –highlighted in yellow boxes.

Based on the analysis of the DSM, the semiconductor product development process can be divided into four major phases.

- Specifications phase
- Design phase
- Manufacturing phase
- Testing phase

The Integrated Device Manufacturers like Intel work on all the four phases while the fabless companies work on the first two phases and outsource the rest. The output of one phase feeds as input for the next phase. For example, the output of the design phase is the net list and it feeds into the manufacturing phase to create working silicon.

DSM analysis provides insights into how to manage complex product development process and also provides information about the extent of modularity involved in the development process. Since the individual tasks inside each of the yellow boxes are sequential and do not depend upon activities outside of the box, the entire phase can be managed independently and can be outsourced. During module integration, the teams will require lots of co-ordination to reduce design errors for high yield manufacturing.

2.9 Conclusion:

The supply and the demand side changes in the industry have led to significant changes in the value chain of the semiconductor industry. As a result a number of new players have emerged offering various specialized services to capture a portion of the value that has been created by the ecosystem. The analysis of the design structure matrix has shed light on the tasks that can be outsourced in a typical semiconductor product development project. The following chapters discuss the drivers and challenges that companies face in outsourcing the tasks that have been identified in this chapter, namely design and manufacturing.

3 CHAPTER 3: INDUSTRY EVOLUTION AND HISTORY OF PROCESS IMPROVEMENTS

3.1 Introduction:

During the past three decades, the semiconductor industry has experienced rapid advances in technology, rising costs in production and operations and declining prices for finished products. Not coincidentally, during this period the industry has evolved as a result of vertical specialization in semiconductor design and manufacturing, as seen by the growth of "fabless" design and marketing firms and "foundries" that contract the production of their designs. The increased vertical specialization has resulted in pushing the R&D burden to equipment suppliers to develop new manufacturing process "modules" that integrate and complement the tools they produce. The vertical separation has also resulted in further decomposition of the players that create license and trade "design modules" for use in integrated circuits (Linden and Somaya, 2003) [32]. In this chapter, the trends in the process improvements and how these trends have shaped the industry are discussed.

3.2 Evolution of the Industry Structure

The semiconductor industry started with the invention of point-contact transistor at Bell Laboratories in 1947, nearly 60 years ago. This invention became a source of new ideas for several large and small firms and many critical innovations eventually emerged. Texas Instruments (TI), which started as the seismographic instrument company in 1930, entered this industry couple of years after the invention and was followed by Fairchild, Shockley Laboratories, IBM, Motorola and Sony. The first monolithic IC was demonstrated at Fairchild semiconductor and Texas Instruments[33]. Table 4shows the major milestones in the early semiconductor history.

[32] E-business and the semiconductor Industry value chain: Implications for vertically specialization and integrated semiconductor manufacturers by Jeffrey T Macher, David. C. Mowery and Timothy S.Simcoe
[33] Fabless semiconductor implementation, book written by Rakesh Kumar

Year	Milestone
1947	Point-contact transistor invented at Bell-Labs
1948	First transistor unveiled by Bell Labs
1954	TI announced first commercial transistor
1955	Shockley semiconductor was founded and Motorola unveiled its first commercial power transistor
1957	Robert Noyce and 7 others that left Shockley founded Fairchild Semiconductor
1958	First Monolithic IC invented at Fairchild by Robert and Jean and at TI by Jack
1967	TI announced its first calculator
1968	Intel founded by Robert Noyce and Gordon Moore
1969	AMD founded by Jerry Sanders
1971	Intel announced first 4-bit microprocessor (4004)

Table 4 : Major Milestones in the early semiconductor history[34]

Since the advent of the integrated circuit, the trends in device technology have been in the direction of microminiaturization[35]. The complexity of IC's has increased by over five orders of magnitude at the rate of roughly doubling every 12 months initially, then every 18 months (1975 to mid 1990's) and now every 24 months[36]. This has largely involved a continual improvement in production engineering technology rather than advances in solid state physics.

In the first two decades of the computer and semiconductor industries, large integrated producers such as AT&T Bell Labs and IBM, designed their own photolithographic devices, manufactured the majority of the capital equipment used in the production process and utilized internally produced components in the manufacture of electronic computers and computer software that was leased or sold to the customers [Braun and MacDonald, 1978]. The vertically integrated companies dominated the industry and the idea of separating the design and manufacturing houses was considered absurd as no company was willing to spend millions of dollars in

[34] Major Milestones in the Early Semiconductor Industry - Fabless semiconductor implementation by Rakesh Kumar
[35] A history of the world semiconductor industry by Peter Robin Morris
[36] Fabless semiconductor implementation, book written by Rakesh Kumar

manufacturing equipment and absorb major losses during recessionary periods. Some major semiconductor companies offered foundry services to fill unutilized fab capacity until merchant foundries entered the market with the idea of manufacturing from different sources to balance the ups and downs of the semiconductor cycle. Figure 10 shows the evolution of different players in the fabless value chain. Outsourcing manufacturing to merchant foundries started in late 1980's.

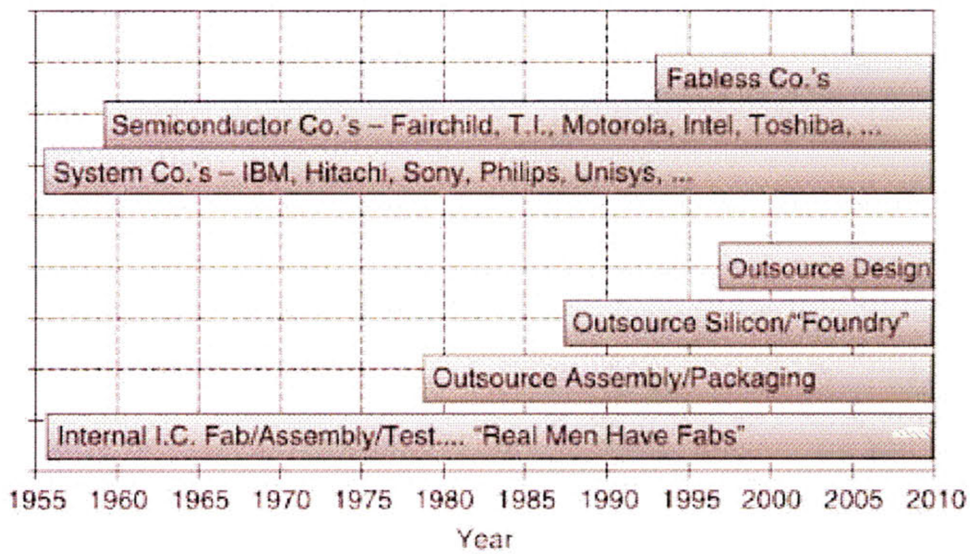


Figure 10 : Evolution of Outsourcing[37]

Chips and Technologies was the first company to adopt this business model in mid 1980's and was followed by Taiwan Semiconductor Manufacturing Corporation (TSMC). TSMC provided a unique model of serving the fabless semiconductor vendors so that wafer shortages during peak cycles can be fairly shared. While profitability was a major bottleneck for the merchant foundries, TSMC achieved a high degree of profitability from the economies of scale associated with high yields, volume and amortization of R&D costs.

At the same time, companies such as Unisys came up with alternate business models to develop IC's leveraging leading edge process technology and design tools to get the best competitive advantage for their systems. They entered into partnerships in 1981 with companies such as Intel and later with Motorola to leverage their process technologies. Such partnerships aided faster turnarounds when making engineering changes to designs and also helped focus internal

[37] Evolution of outsourcing and the fabless industry – Fabless semiconductor implementation by Rakesh Kumar

capabilities to specific needs of the system companies such as design and verification. By 1990, Unisys became the first system manufacturer to shut down its wafer fab and outsource their manufacturing to merchant foundries.

3.3 Gate Array ASIC Industry is born

The demand for microprocessors, memory products and other semiconductor products surged due to the introduction of personal computers. The ASIC[38] (Application Specific Integrated Circuits) industry was born as a way to consolidate small scale and medium scale integration functionalities on to a single chip. These companies came up with tools and methodologies to convert logic description into "Gate Arrays". Gate array design is a manufacturing method in which the diffused layers, i.e transistors and other active devices, are predefined and wafers containing such devices are held in stock prior to metallization, in other words, unconnected[39]. As the ASIC suppliers added more features in a single product, there was a strong need to automate the design and verification of the features to create a product of high quality. This led to the birth of EDA (Electronic Design Automation) industry.

3.4 Birth of EDA Industry

The importance of Computer Aided Design (CAD) tools was recognized early on as designers were challenged by the complex nature of the chips. There was a strong need to

- Automate ways to design to improve the productivity of the designer.
- Reduce the time to market
- Develop high quality and reliable products.
- Find better ways to track and verify the complete set of features that the chip supports before taping out the chip for manufacturing
- Find better ways to test the product
- Increase modularity

[38] ASIC- Integrated Circuit customized for a particular use rather than for general-purpose.
[39] http://en.wikipedia.org/wiki/Application-specific_integrated_circuit

Initially, the system companies developed their own in-house CAD tools, libraries and functions. As the design challenges escalated further with increasing transistor densities, the EDA industry was born in the late 1980's with the merger of Solomon Design Associates (SDA) and Electronic Computer Aided Design (ECAD), which was later renamed as Cadence Design Systems. Since the late 1990's, the landscape for EDA has rapidly expanded to cover a broad range of tasks that include system specification, transaction level modeling and behavioral synthesis as well as tasks related to manufacturing and post silicon activities such as Design for Manufacturability (DFM), Design for Reliability (DFR) and post-silicon debug.

3.5 IP: Chips in Everything

One of the quickest way to design a chip is to not to design it all[40]. Most big semiconductor firms include a fair amount of reused, borrowed or licensed design blocks in their design. The availability of design blocks from one technology to another can be a major asset in reducing time to market, cost and risk. Since the mid 1990's design blocks were created by independent companies solely for the purpose of selling or licensing to big companies. The increasing complexity of chips has stimulated the need for IP. There are a few profitable IP companies such as ARM, MIPS and DSP group that license partial chip designs and collect a royalty.

Although it is an attractive alternative for makers of large chips to buy parts of design from outside IP vendors, it isn't all smooth sailing. Outside IP is designed to cater to the largest possible audience and hence it is somewhat generic. Potential customers who look for something more specific license soft IP (amendable) cores. The alternative to a soft IP is hard IP, which cannot be altered or modified. Early IP vendors almost always delivered hard IP's but the trend has moved towards soft IP's due to the degree of specialization among chips.

3.6 Need for Yield Management and Process Control Solutions

Several factors inherent in the semiconductor industry such as declining prices, shorter life cycles, and shrinking geometries challenged the IDM's and independent foundries to effectively address the manufacturing complexities and remain profitable. There was a critical need for effective yield management and process solutions to integrate defect detection and management

[40] The essential guide to semiconductors,book written by James L Turley

into the production line to address the challenges. High yield can produce a direct and tangible impact on the bottom line.

There are two ways to increase the yield

- By improving the control of the manufacturing process in the foundries
- By designing the circuits to minimize the effect of inherent variations of the process on performance – Design for Manufacturing

KLA Instruments founded in 1976 pioneered the yield management market with an automated inspection system to control the manufacturing process in the foundries. The company merged with Tencor Instruments in the late 1990's, creating KLA-Tencor, to broaden its product offering and became the first yield management group to provide its foundry customers with expertise in increasing yield through engineering consulting services.

3.7 Emergence of Fabless Companies

The emergence of ASIC's, merchant foundries and EDA encouraged entrepreneurs to realize a way to fabricate their logic designs into silicon without having or designing automation tools and owning a semiconductor wafer fab. Leveraging the availability of tools and methodologies independent fabless companies started to launch in the early 1990's. Junk-bond financed-leveraged buyouts and corporate raider takeovers also resulted in big corporations being torn apart because the sum of the constituent parts was worth more than the whole[41]. The spillover effect was that corporations divested investments in areas that offered a competitive advantage. This trend challenged the long-held belief in market power gained through vertical integration[42].

[41] Understanding Fabless IC technology by Jeorge S,Hurtarte, Evert A.Wolsheimer, Lisa M. Tafoya
[42] Understanding Fabless IC technology by Jeorge S,Hurtarte, Evert A.Wolsheimer, Lisa M. Tafoya

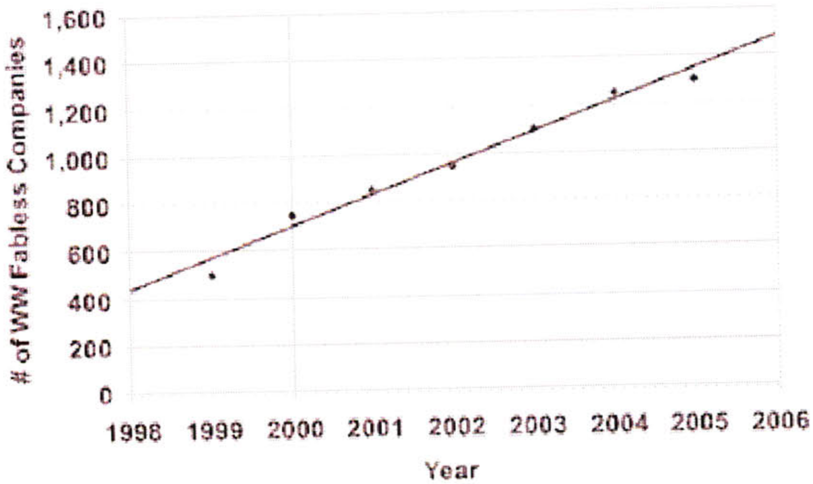


Figure 11: Growth in the number of Fabless Companies

Figure 11 shows the growth in the number of fabless companies. The symbiotic relationships between the foundries and fabless companies stirred the growth in the number of fabless companies and have pushed each other to higher levels of competency.

The first fabless companies like Chips and Technologies and Brooktree Corporation faced many hurdles to design their IC's, fabricate the silicon, package and test them. These companies were able to successfully prove to the World the feasibility of a distributed supply chain for the design and manufacturing of IC's using COT (Customer Owned Tooling) approach. The term "tooling" refers to the glass or quartz masks used in the fabrication process. As advanced silicon packaging and assembly capabilities became available, the growth in the number of fabless companies accelerated. The combined elements of supporting the design infrastructure industries are referred to as "Design Ecosystem". The design ecosystem includes the Intellectual Property (IP) vendors and EDA software vendors. Ecosystems that have evolved in the various parts of the supply chain supports fabless business model. The figure 12 below shows the support structure and their salient features.

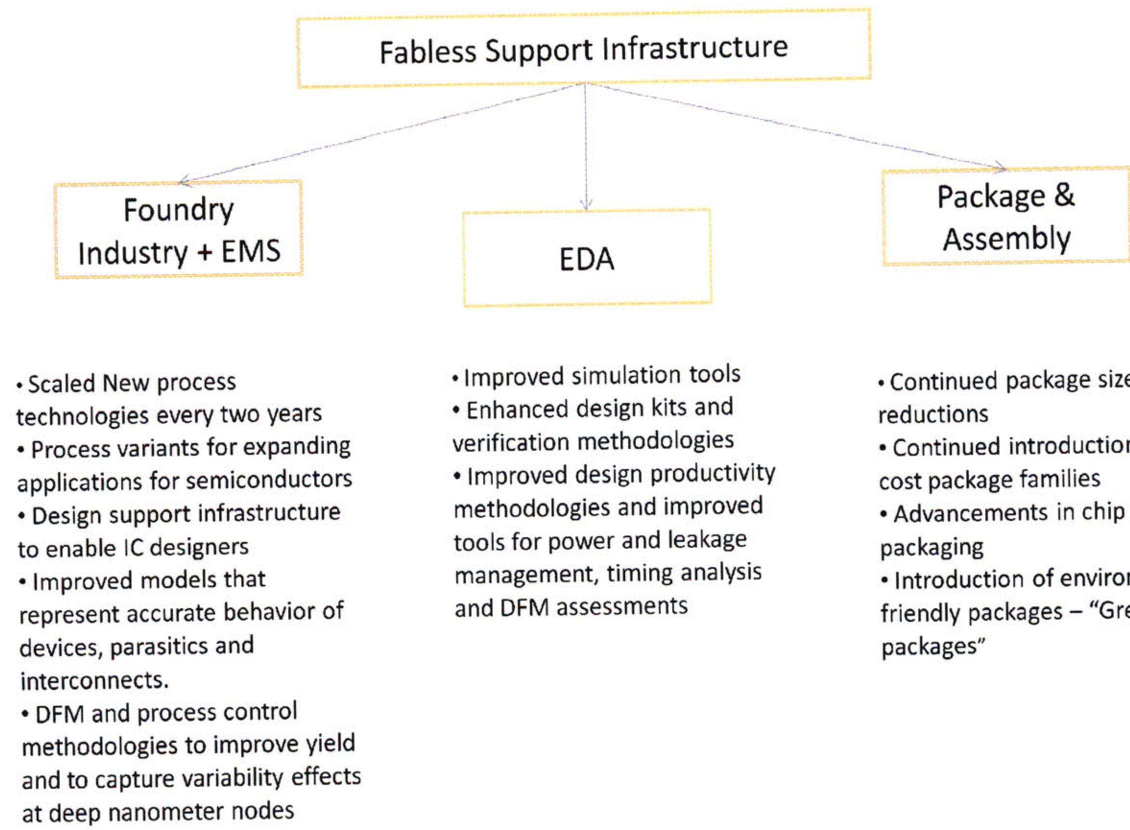


Figure 12: Fabless Support Infrastructure

3.8 Interactions in the Fabless Ecosystem

The trend towards smaller geometries requires companies in the fabless ecosystem to work together establishing a high level of interdependence. EDA companies work closely with IC foundries and packaging suppliers to enable designers to harden designs into silicon, to design a compatible silicon package and to provide a scalable, high volume solution. They also interact with foundries to assist in building models of the process technology and to enable the designers to use these models to predict the behavior of the circuit in the silicon. The EDA companies, IP vendors and the foundries collaborate in the development of the process technology. Figure 13 shows the interaction among the players in the fabless ecosystem.

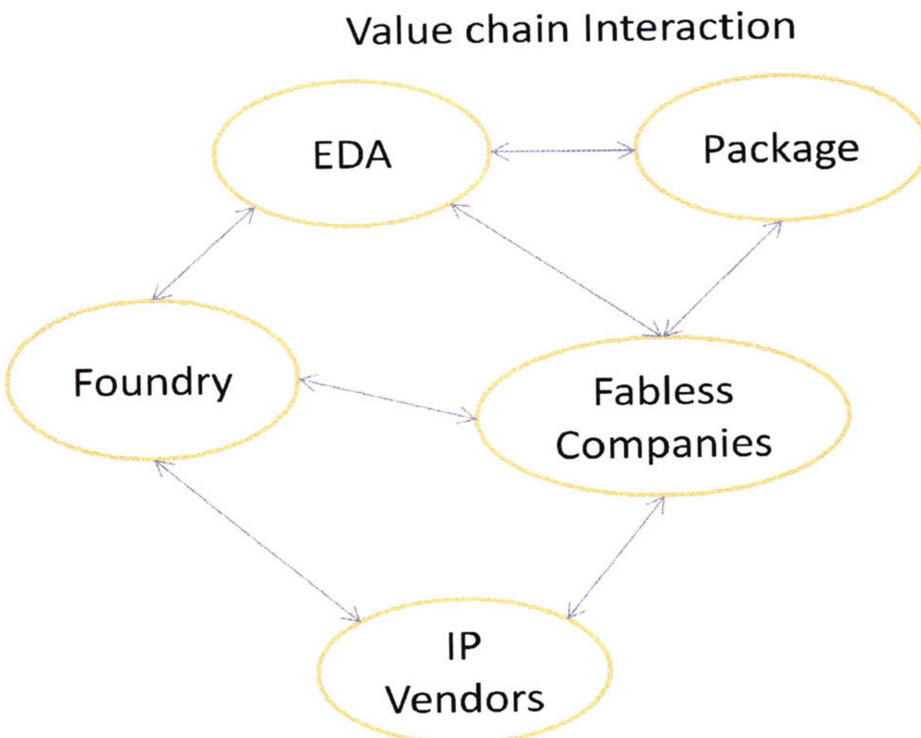


Figure 13: Interactions in the Fabless Ecosystem

3.9 Forces Supporting Evolution of the Industry Infrastructure

The evolution of the semiconductor industry has much to do with the emergence of new fabless business model and supporting ecosystem. The proliferation in the number of players in the ecosystem, particularly in the last three decades reflects the influence of market related and technological factors. The semiconductor design and production firms exploit economies of scale and specialization due to the rapid expansion of markets for semiconductor devices. The expanding range of potential end-user applications for semiconductor has created additional opportunities for entry by specialized design firms. The design cycle for semiconductor products has become shorter and products life cycle more uncertain, making it more difficult to determine whether demand from a single product will fully utilize a fabrication facility, and increasing the risks of investing in a new fabrication facility dedicated to a particular project[43].

Another factor that drives the emergence of new players in the ecosystem is due to "network effects". The standardization around a single production technology and the resulting improvements in complementary design software for layout and simulation has led to these effects. Complementary Metal Oxide Semiconductor (CMOS) processes dominate the manufacturing process technology for digital semiconductor devices. The emergence of this technology standard has facilitated the division of labor between product designers, who are able to operate within relatively stable design rules, and process engineers, who are able to incrementally improve new process technologies[44].

Finally, the emergence of new technological innovations is also supporting the idea of vertical disintegration. The open standards architecture of personal computers has contributed to the development of standardized interfaces among components that in turn has facilitated specialized production of individual component designs and component manufacturing. Advances in electronic design automation and electronic manufacturing service tools have also played a huge role that has facilitated the exchange of design data between fabless companies and manufacturing foundries.

3.10 Conclusion

Fabless business model has transitioned from an opportunistic initiative to a strategic imperative. Huge capital requirement in owning a manufacturing plant, advances in EDA, IP and EMS industries have catalyzed the adoption of this model. The fabless model has continued to expand and going forward it is hard to imagine that a new semiconductor company would commence as a manufacturing company.

[43] E-business and the semiconductor value chain – white paper by Jeffrey T Macher, David C.Mowery and Timothy S. Sincoe
[44] E-business and the semiconductor Industry value chain: Implications for vertically specialization and integrated semiconductor manufacturers by Jeffrey T Macher, David. C. Mowery and Timothy S.Simcoe

4 CHAPTER 4: OUTSOURCING SEMICONDUCTOR R&D

4.1 Introduction

Globalization by multinational companies began in the early 1960's by expanding sales, manufacturing and operations overseas. In the early 1980's, companies started with the trend of outsourcing R&D efforts, with many cost advantages and price competition associated with them. The electronic industry has put immense pressures on the R&D capabilities of multi-national companies. Development time has a direct impact on the bottom-line achieved by a newly developed product. Given the highly competitive nature of the semiconductor market and the location of manufacturing facilities in the Asian region, companies began to outsource to third party design houses in Asia. Although this trend has not yet reached the level of manufacturing outsourcing, it will become more of a trend with one-fifth of the companies outsourcing their R&D[45]. This chapter describes the trend among semiconductor companies to outsource research and development efforts to low cost destinations. Outsourcing R&D refers to product engineering and application development and does not include business process outsourcing (BPO).

4.2 Impact of Outsourced R&D for Organizations

Outsourcing brings significant cost, marketing and strategic advantages along with it. Companies strive to attain a strategic balance between performing R&D in-house and outsourcing, as R&D remains as the last on the list of processes that can be scrutinized to cut costs. The formation of R&D networks had proved more productive as a combination of different regions in the world and their technological strengths utilized for R&D had yielded high levels of productivity[46]. R&D in multiple locations across different geographies and time zones means greater motivation, rapid innovation rates and fewer errors. The percentage of R&D outsourced varies from company to company. Some companies design their high-end electronic products in-house

[45] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

[46] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

and outsource designs that are not viewed core competency. Companies are keen on protecting their core intellectual property and adopt unique outsourcing strategies to safeguard the same. Although there are standards for this, they are not sufficient to avoid any technology leakage. On the other hand, ODM's supply products to major brand names while outsourcing their design and manufacturing and this has led to lack of trust between the buyer and the outsourcing supplier.

Figure 14 shows the SWOT analysis of outsourcing R&D.

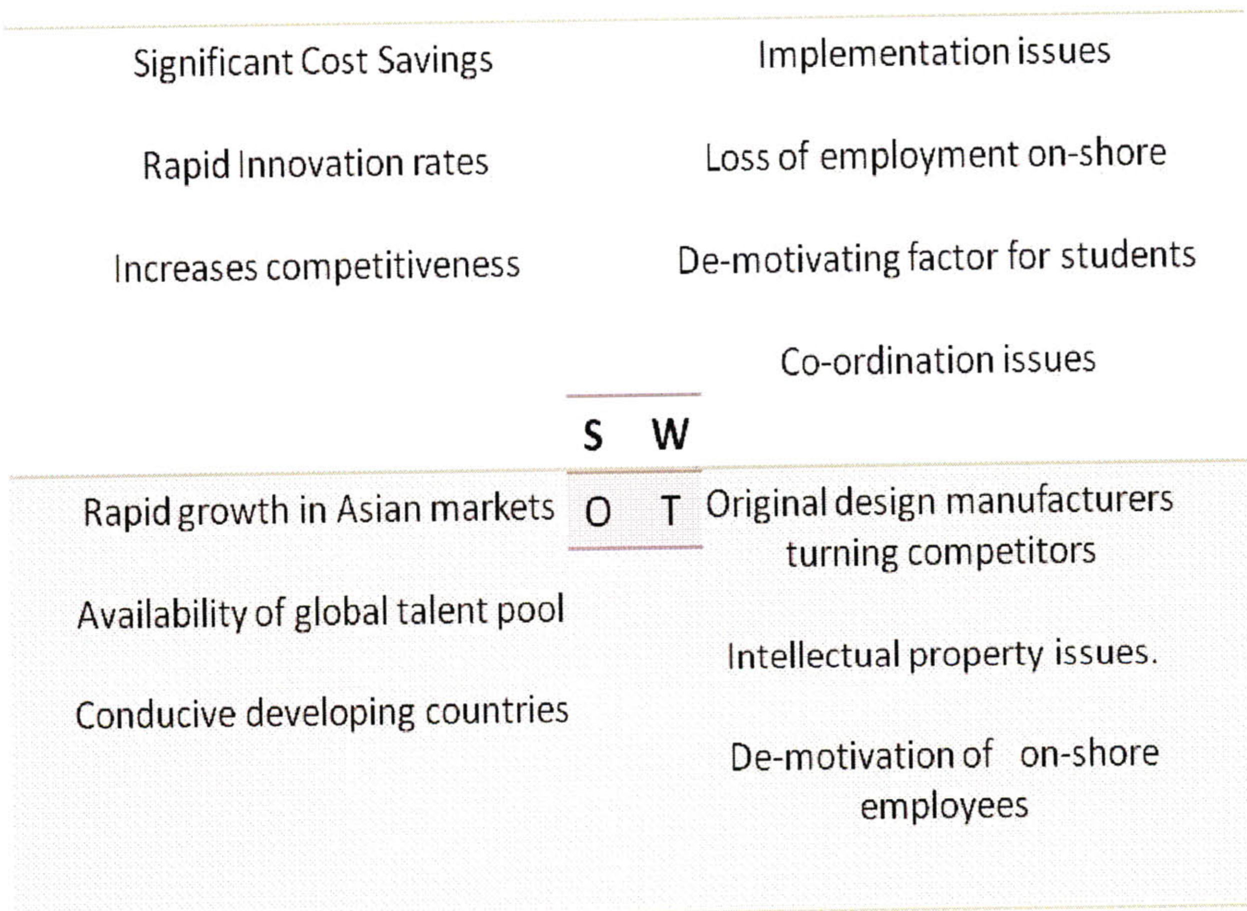


Figure 14: SWOT Analysis for Outsourcing R&D[47]

[47] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

4.3 Drivers for Outsourcing Electronics

- **Development of Efficient R&D Strategies** - Companies take several initiatives to develop efficient R&D strategies. In semiconductor industry, companies ensure that their off shored R&D centers are situated in the vicinity of emerging markets. R&D centers are also created to work closely with outsourcing suppliers that design products to production. The model of outsourcing also functions based on close interaction with customers for feedback.

- **Talent pool for electronics:** Asian region is well known for their pool of talent and human resources, especially in India and China. With R&D being outsourced to these countries, corporations face a stiff competition in retaining the services of highly skilled engineers. This phenomenon is due to the gradual increase of salaries and high demand for talent.

  According to Ernst and Young, "*For a good portion of the 1970s, corporations were able to retain their overseas resources, from junior to senior level officers; however, with the outsourcing trend growing and MNC's jumping on the band wagon, more opportunities are created for these engineers and scientist. Many engineers and scientists have built their own networks, so the level of opportunity increases. Areas providing opportunities and competition specifically are: Bangalore, Shanghai, and Beijing*".[48]

- **Conducive environment for R&D in developing countries:** Developing countries are taking significant initiatives to drive commercial and academic R&D and are spearheading the trend of modern research[49]. China and India are building new engineering centers and improving their existing R&D centers year by year. Figure 15 shows the main factors that draw in R&D in outsourcing destinations.

[48] http://w.cba.neu.edu/igim/thoughtLeadership/working_papers/igim_wp05-04.pdf
[49] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

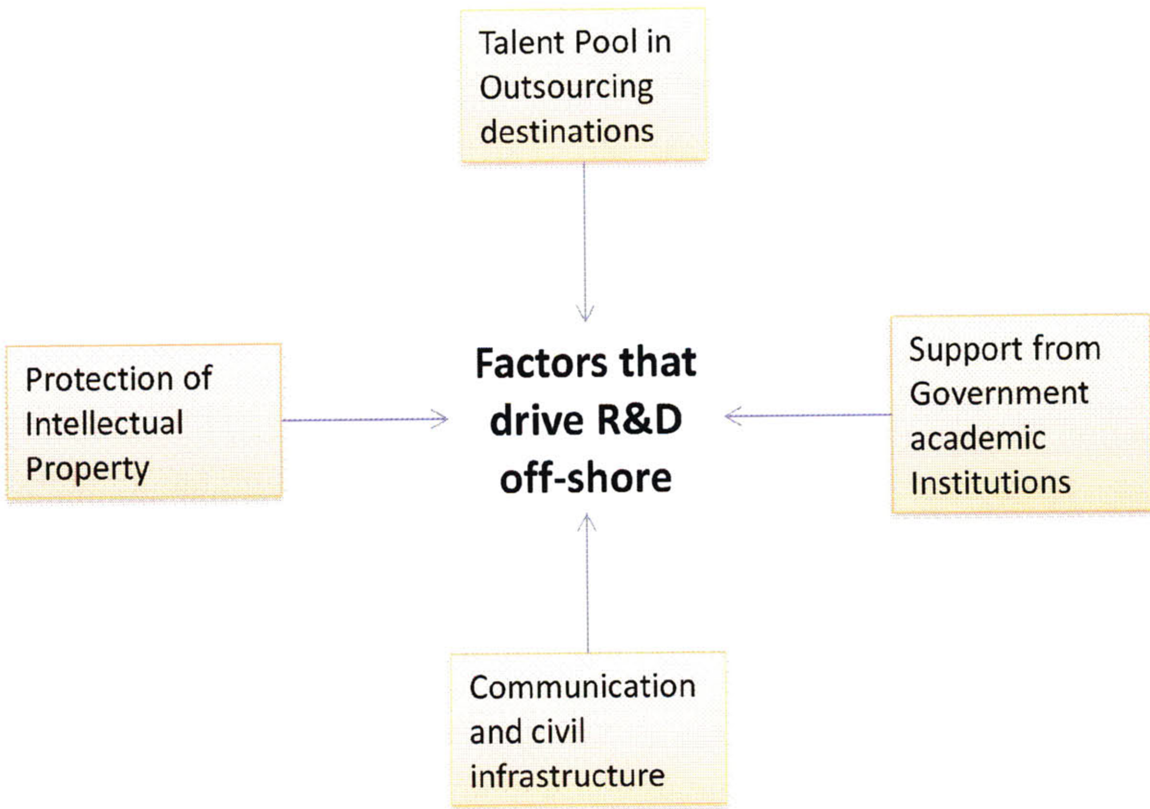


Figure 15: Factors that drive R&D Off-Shore

- **Time to Market and Market Segmentation:** Time to market and time to volume are two major factors that drive outsourced R&D[50]. Electronic products follow a rapid trend of becoming a commodity. Time to market for an electronic product since the onset of R&D outsourcing has reduced drastically. For example, the time to market for mobile phones has reduced to 4 to 6 months[51]. A delay in time to market of the product would reduce the competitiveness of the product in the market. Because of this round-the-clock R&D by utilizing the services of R&D centers situated in different locations around the world is one strategy that multinational companies pursue.

[50] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition
[51] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

4.4 Challenges of Outsourcing R&D

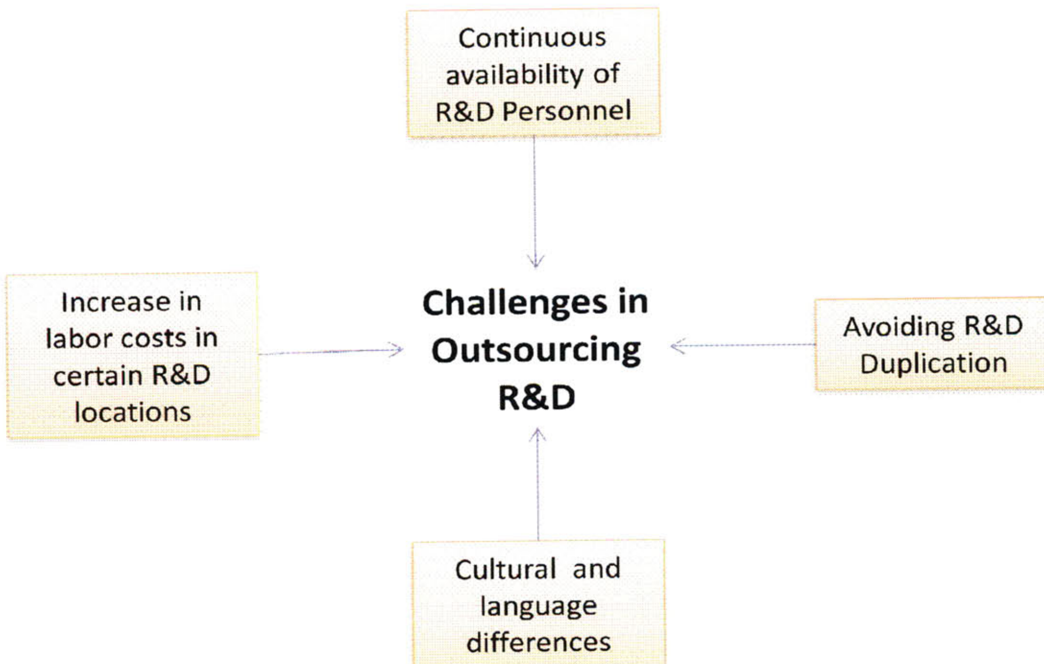


Figure 16: Challenges in Outsourcing R&D

- **Continuous availability of R&D Personnel**: Outsourcing has raised concerns regarding continuous and future availability of R&D personnel. As R&D moves to offshore destinations, it is feared that it may further drive a loss of on-going development of skilled force. In semiconductor industry, since the R&D has been outsourced to India and China there is wide perception that there would be losses in R&D jobs in home countries, with this trend also driving the reduction of salaries in these countries. Recently there has also been a backward flow of engineers and scientists returning to their home countries from countries such as United States due to attractive salaries and opportunities[52].

- **Avoiding R&D duplication:** This is an organizational problem where the central command for R&D should plan the activities in each facility depending upon the availability of capabilities in different facilities. Although duplication is wasteful, it may sometimes be necessary to have parallel efforts to speed up the R&D process

[52] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

- **Cultural differences and Language Barriers:** A major issue in dealing with outsourcing is the cultural and language barriers between the contracting firm and the outsourcing firms' employees. A poor understanding of these can lead to severe problems.

4.5 Design Services Business Model

Figure 17: Design Services Business Model

The design services model in semiconductor industry includes the activities and players mentioned in figure 17. The OEM's define the system level specification for the product and then outsource it to a design supplier for implementation and testing. The handoff involves NDA (Non-Disclosure Agreement) between both the parties. After the features are designed and validated the design is either sent back to the OEM or it is sent to the foundry for manufacturing.

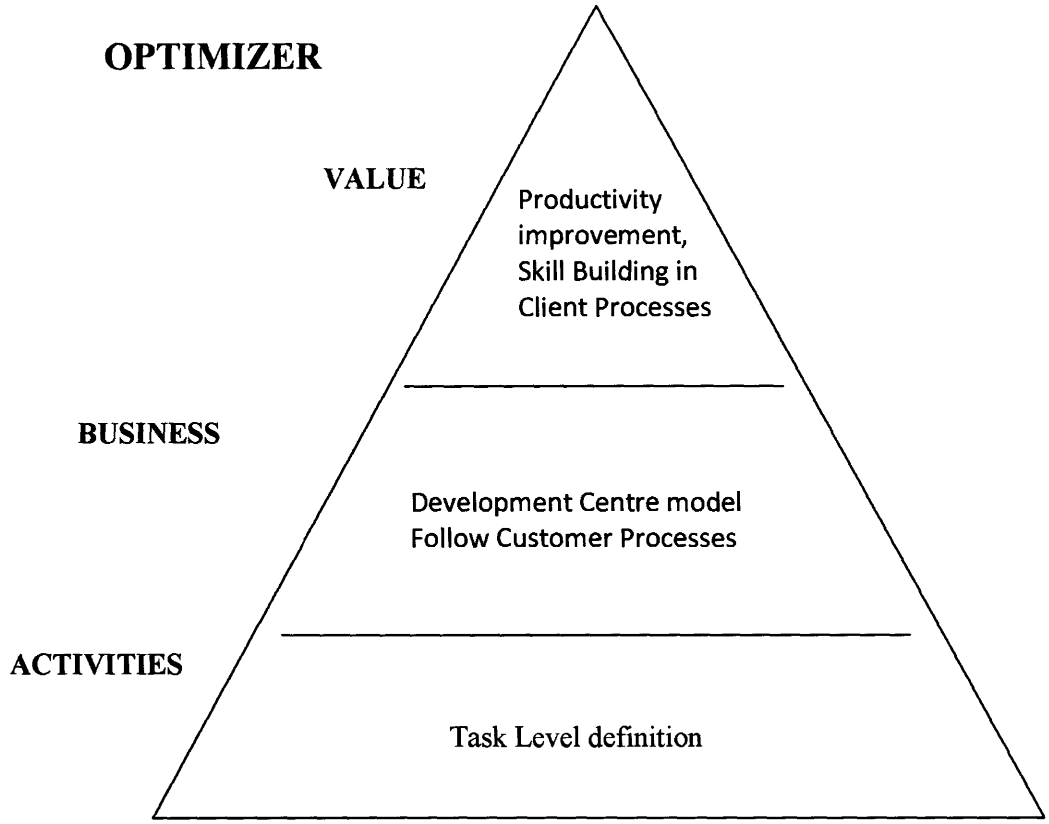
Design service companies are shifting focus from providing custom design services to full product realization services in order to serve medium and small semiconductor companies. The OEM's use in-house design teams and third party service providers based on project needs. OEM's also outsource when there is excessive demand and plenty of opportunity for a particular type of design. For example, if there are two or more projects in a particular technology node, say 65nm, one of the projects might get outsourced. Large OEM's work on multiple strategies to optimize the cost of development and operation and this trend fuels the outsourcing trend. Some OEM's establish partnership with design service companies, in which the design service companies allocate a specific number of employees to work on the job outsourced by the OEM. These groups are called as ODC's (Onsite Development Center).

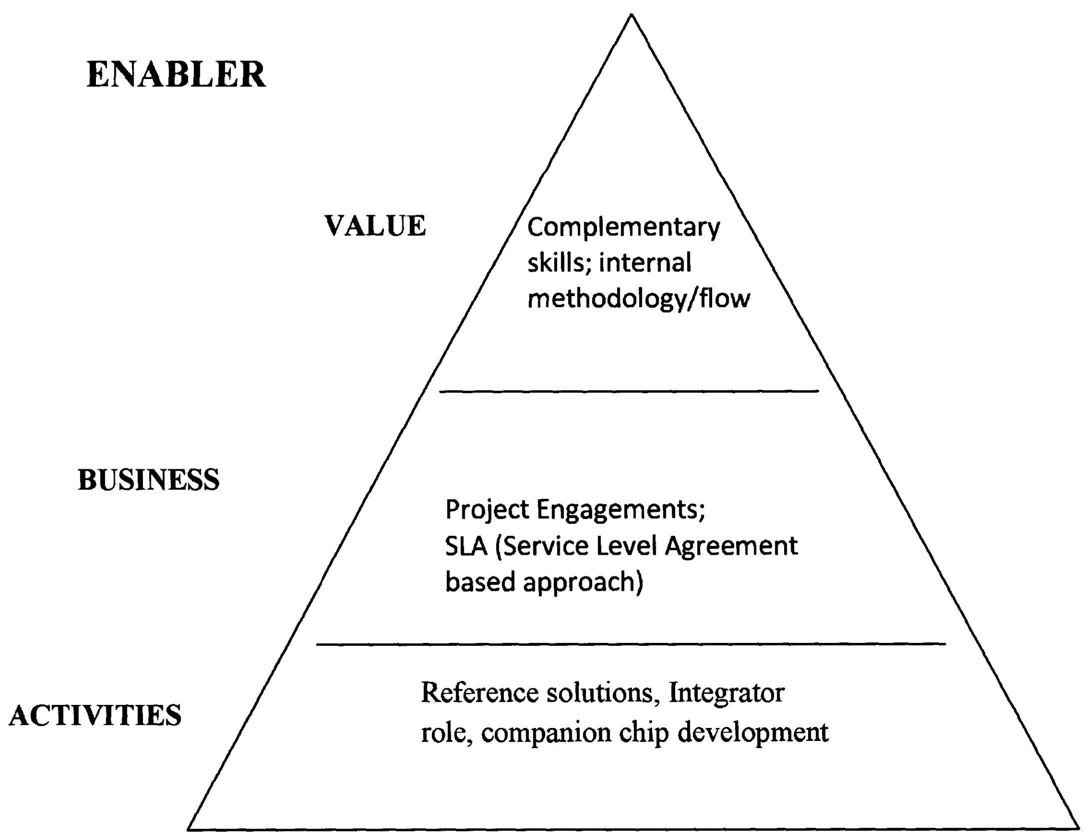
The large OEM's and fabless companies are demanding turnkey ASIC design services and seek help from third party design service providers to take the working silicon to reference design or prototype. To satisfy the increasing demand from their customers, design suppliers provide additional services and are moving up the value chain.

The design service companies provide the following flexible business models for engagement

- ***Time and Material model***
  - In this model the project is customized according to the specifications and customers have to pay for it
  - Since the implementation plan and specifications change frequently, this model is suitable for emerging technology markets
  - This can be an onsite or an outsource engagement as transparency is very high in this model
  - About 70% of all VLSI design services belong to this business category.
- ***Fixed Price Model***
  - In this model the project is designed according to the specifications and the customers pay a fixed price
  - This model is suitable in markets where the specifications are base-lined and the implementation and scope of the projects are clear
  - This model is less flexible than the previous one and it is not suitable for first time engagements
  - Provides framework for a win-win scenario, in which the clients gets deliverables on schedule and within budget.
- ***Dedicated Engagement Model (ODC model)***
  - This model is suitable for companies for long term gains from outsourcing with quick starts and future ramp-up.
  - This model offers complete flexibility in time and budget as the facility will be under client's control.
  - The customer pays for pre-developed products, process setups, materials and resources needed to be deployed for the project.
  - This model can be converted to a fixed price model once the resources gain familiarity with the product specifications and for incremental innovation projects.

All these models can be used for both onshore and offshore outsourcing projects.


OPTIMIZER
VALUE
Productivity
improvement,
Skill Building in
Client Processes
BUSINESS
Development Centre model
Follow Customer Processes
ACTIVITIES
Task Level definition


ENABLER
VALUE
Complementary
skills; internal
methodology/flow
BUSINESS
Project Engagements;
SLA (Service Level Agreement
based approach)
ACTIVITIES
Reference solutions, Integrator
role, companion chip development

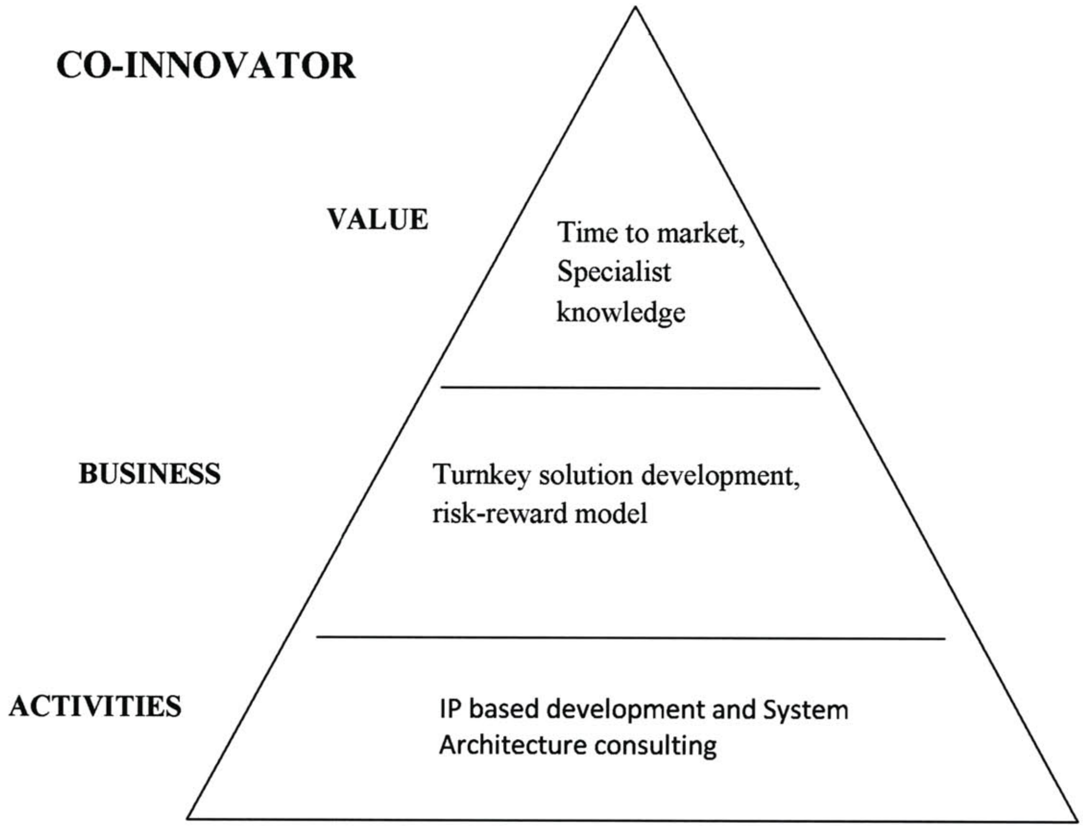


Figure 18: Optimizer – Enabler – Co-Innovator Model

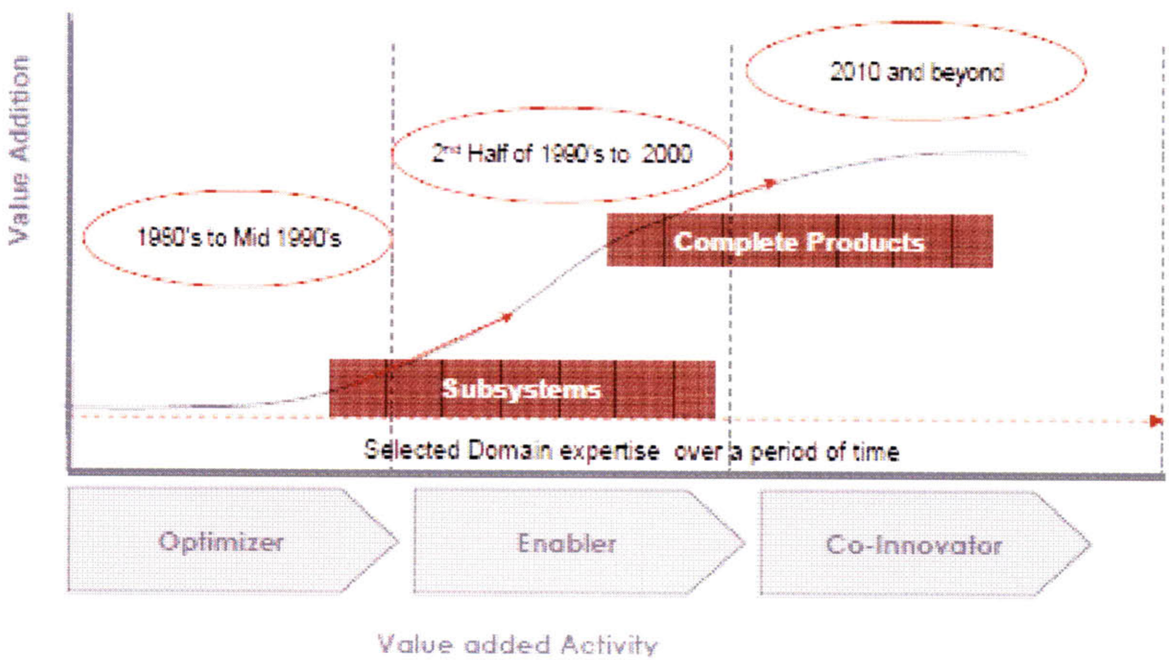


Figure 19: Evolution of Optimizer-Enabler-Co-Innovator Model

Figure 18 shows the three different models for outsourcing – Optimizer, Enabler and Co-innovator from value, business model and activities standpoint. The big OEM's are playing the role of Co-Innovators along with the design service providers, who are moving from being optimizers to become enablers and in some cases, co-innovator[53]. New start-up companies offering design services fall under the optimizer's category as they offer specific activity across the design value chain, adding very less value to the customers. Some mature design service providers offer value-added services such as chip integration, reference models, and others, thereby performing the role of enablers. Figure 19 show the evolution of different business models over time. Design service business generates lower value than product-based work businesses and can act a springboard toward product development and a fabless business model.

4.6 Activities that can be Outsourced

The decision about what R&D activities can be outsourced can be analyzed using a simple framework proposed by Balachandra and Friar in 1997. This framework suggests that all the projects are not the same and have differences depending on the combination of the three dimensions – Market (Existing or New), Technology (Familiar or Unfamiliar) and innovation (Incremental or Radical), represented as a cube, called the Contextual cube for NPD and R&D projects.

As seen from the figure below (figure 20), if the R&D activities are geared towards developing a new product development targeted for an existing market with a familiar technology and is an incremental innovation, the activities can be easily outsourced. The tasks associated with these activities are usually routine that can be budgeted in terms of both time and cost, and can be managed from a distance. On the other hand R&D activities targeting a new market involving an unfamiliar technology and incorporating a radical innovation should be done in-house. These activities require a more flexible approach with regards to time and cost and the management has to react quickly to change directions of the project.

[53] Frost and Sullivan Report on outsourcing of R&D in Electronics Industry, Dec 2006 edition

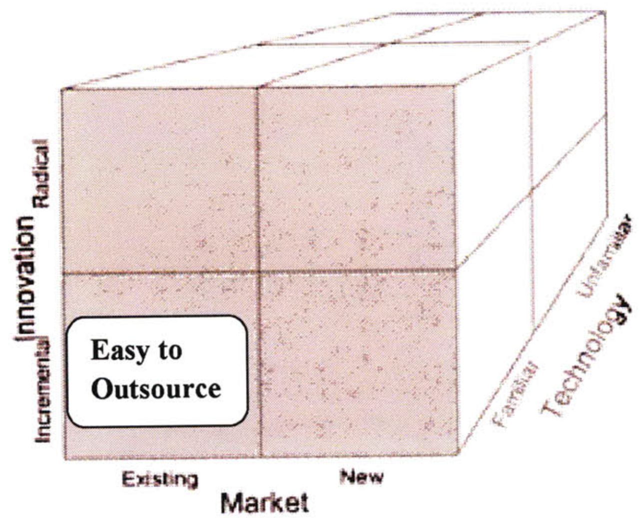


Figure 20: Contextual Cube for R&D[54]

Table 5 shows the different outsourcing patterns exhibited by companies in personal computer and mobile industry. The product development activities that can be outsourced can be broadly classified into specification, design, verification, physical design and manufacturing. Many companies in the PC industry design their Integrated Circuits in-house to avoid technology leakage and outsource verification and physical design work that consumes a greater portion of the project schedule – Nearly 70% of the product development cycle. By outsourcing verification, the customers can better track verification costs and quality control over the skill and knowledge of engineers devoted to verify complex systems and designs[55]. Outsourcing verification and physical design also solves a company's dilemma of allocating resources to recruiting top engineers and outsourcing firms can provide with verification expertise to those customers located in remote areas who cannot attract talented engineers. Similarly in the mobile industry, the companies outsource activities that involve quicker results, faster time to market and that generate greater return on investment.

Successful fabless companies in semiconductor industry have found new design technologies or features targeting an existing market using a familiar process technology for manufacturing. For example, Nvidia, a leading player in graphics processing units and chipsets targeted an already

[54] Balachandra, R. and Friar, J.H. (1997) Factors for Success in R&D Projects and New Product Innovation: A Contextual Framework, EM-44, 3, 276-287

[55] http://electronicdesign.com/content.aspx?topic=as-ics-grow-more-complex-design-verification-will-&catpath=eda

existing market where big players like ATI were dominating and were able to capture market by introducing a graphic chip with hardware transform, lighting and shading features.

PC Market			Mobile Market		
	Activities	**In-house/Outsourced**		**Activities**	**In-house/Outsourced**
Intel	Specification	Internal	**Nokia**	Specification	Internal
	Design	Internal		Design	External
	Verification	Internal and External		Verification	External
	Physical design	Internal and External		Physical design	External
	Manufacturing	Internal and External		Manufacturing	External
TI	Specification	Internal	**Motorola**	Specification	Internal
	Design	Internal and External		Design	Internal
	Verification	Internal and External		Verification	Internal and External
	Physical design	Internal and External		Physical design	Internal and External
	Manufacturing	Internal and External		Manufacturing	External
AMD	Specification	Internal	**RIM**	Specification	Internal
	Design	Internal		Design	Internal
	Verification	External		Verification	Internal
	Physical design	Internal		Physical design	Internal
	Manufacturing	External		Manufacturing	External
Samsung	Specification	Internal	**Apple**	Specification	Internal
	Design	Internal		Design	Internal
	Verification	Internal		Verification	Internal
	Physical design	Internal		Physical design	Internal
	Manufacturing	Internal		Manufacturing	External

Table 5: Outsourcing models adopted by PC and Mobile handset Manufacturers.

4.7 Conclusion

Outsourcing R&D is a growing phenomenon with the emergence of India and China as producers of young talented people skilled in technology and sciences. Companies that outsource to these countries derive significant benefits in terms of continuous R&D and comparative advantage in terms of wages and proximity to manufacturing plants. Utilizing these human resources as a part of globalization for doing R&D activities makes economic sense. Also, the location of R&D facilities in off-shore destinations would help in better understanding of the local market preferences and can lead to developing products suited for those locations.

5 CHAPTER 5: OUTSOURCING MANUFACTURING

5.1 Introduction

The semiconductor industry is fundamentally dependent on the manufacture of silicon integrated circuits. These products are used in solid state computing, telecommunications, automotive, consumer electronics and in numerous other industries. Manufacturing was the first operational area to be outsourced. No single company has managed to manufacture all of its parts and companies often have to make decisions whether to buy or make it in-house. While electronics industry has successfully adopted the fabless business model and has consistently performed well, the resulting supply chain problem, ability to remain competitive with integrated device manufacturers and other visibility problems are posing significant challenges to sustain this business model. In this chapter, a brief historical review of outsourcing in electronic manufacturing industry, associated challenges and risks of decoupling and a recent case study of a company that became fabless are discussed.

5.2 Evolution of Outsourcing in Electronic Manufacturing Industry

The vertical manufacturing strategies were the rule for manufacturers of high technology products until early 1990's. In 1990, the global electronics market was worth nearly $100 billion, while less than 5% of all manufacturing was outsourced[56]. Outsourcing the manufacturing started in the mid 1990's when large number of high technology OEM's were re-examining their manufacturing strategies to take advantage of the substitutes available to them to improve performance and reduce equipment, operation and maintenance costs.

Outsourcing in the semiconductor industry has evolved significantly during the past 20 years. The outsourcing supplier would take on manufacturing for specific IC on contract-by-contract basis. Over the time with many such contracts, the contract manufacturers were able to leverage operational expertise, cheap labor and buying power to lower the costs for the OEM's. As the OEM's diversified their product portfolio they were able to negotiate their partnership

[56] Strategic Outsourcing; Electronics Manufacturing Transformation in Changing Business Climate, Report by Accenture, Al Delattre, Tom Hess and Ken Chieh

agreements and achieve greater economies working with a single provider. Such conventional outsourcing served the OEM's well into the mid 1990's when the demand was predictable and products were simple[57]. As products grew more complex OEM's found that they had to increase their capital investment in equipment to keep up with new process technologies, which would reduce their bottom line. The accelerated pace in innovation led to shorter product life cycles and increased pressure to reduce time to market. Customers became increasingly selective and demanding, thereby increasing the difficulty to predict the demand for a particular product.

In response to this trend, large OEM's began to outsource the burden of handing the demand to an upstream player in the supply chain by teaming up experienced partner. This symbiotic partnership also helped OEM's to quickly respond to changes in the market, reduce the time and cost involved in developing new products and free themselves to focus on core competencies, tighten product launching process and be more responsive to customer demand. Instead of adjusting their work force, or start and shutdown operations, the OEM's simply began to adjust the fee structure of the outsourcing agreement.

Such partnerships had led to sharing of risks and partners had to work together to achieve strategic outcomes and increase their profits. The ability of the outsourcing partnership to become a "local enterprise"- in which all the players are virtually synchronized was critical to success [58]. As OEM's entered new markets and increased the number of activities that were outsourced, the contract manufacturers responded by complementing with value added services thus transitioning to Electronic Manufacturing Services (EMS) industry.

5.3 Semiconductor Manufacturing Market

Semiconductor manufacturing involves multiple processes on the silicon wafer resulting in the creation of integrated circuits. The manufacturing foundries perform wafer fabrication services that involve a sequence of photographic and chemical processing steps during which circuit connections are established. Only a few integrated device manufacturers (IDM's) have their own fabs since the cost involved in maintaining and operating them are very high. Most IDM's

[57] Strategic Outsourcing; Electronics Manufacturing Transformation in Changing Business Climate, Report by Accenture, Al Delattre, Tom Hess and Ken Chieh

[58] Strategic Outsourcing; Electronics Manufacturing Transformation in Changing Business Climate, Report by Accenture, Al Delattre, Tom Hess and Ken Chieh

outsource the manufacturing to Asian foundries as a cost-cutting measure. This trend has resulted in a steep growth for the Asian semiconductor manufacturing market. Other influencing factors in the growth of this market include the increase in the demand for electronic products within Asia and migration of IDM's to fabless model.

The Asian semiconductor manufacturing market has an expected CAGR of 15.2% from 2006 to 2010 and the revenue at the end of the forecasted period is estimated to be $33 billion[59]. The communications and consumer electronics are the key drivers this growth in Asian countries.

The foundry types can be classified into two different categories

- Large Foundries with latest process technologies and strong presence in manufacturing – TSMC (Taiwan Semiconductor Corporation, SMIC (Semiconductor Manufacturing International Corporation). Chartered Semiconductor Manufacturing and United Microelectronics Corporation.
- Medium and Small foundries focusing on a particular technology segment such as 90nm, 65nm etc – Advanced Semiconductor Manufacturing Corporation (ASMC), CSMC Technologies, DongbuAnam Semiconductor Ltd, MagnaChip semiconductor, Vanguard International Semiconductor Corporation etc

5.4 Changes in the Electronic Manufacturing services industry

The following are the challenges that affect the development of the market or competitors in the market.

- **Reluctance to invest in Cutting-Edge Technologies** – Upgrading to new process technologies is a capital intensive process. The companies that invest in cutting edge technologies should restructure their internal processes for mass production and for better yield. Also, they need to establish a new customer base for new technologies to increase their revenues.

[59] F&S report on Electronic Manufacturing Services, 2007

- **Increase in packaging material costs** – Materials used for packaging such as gold and copper are very expensive and may cost in the range of 30 to 60 percent of the total product costs[60]. The costs remain relatively high and fixed albeit at times subcontractors get volume discounts on bulk purchases.

- **Shorter Product life Cycles** – The increased pace in innovation has led to shorter product life cycles and increased pressure to make it to the market first before competition. Since OEM's select foundries based on their technology and mass production capabilities the foundries are expected to be updated to compete with competitors to seize opportunities.
- **Competition** – Electronic manufacturing services industry face stiff competition from domestic and international players. This intense competition has led to price competition and has dampened the profit margin of EMS providers.

- **Profit Sharing with ODM's** – The Original Design Manufacturers (ODM) pose big threat to the EMS industry. ODM's have a higher bargaining power with OEM's when compared to EMS and retain any savings incurred in the total cost of the product. Their profit margins have been traditionally higher than that of EMS.

- **Managing Supply Chain** – Customers have become more selective and forecasting the demand has become a major challenge in this industry. Due to lack of visibility in the demand, EMS providers manufacture and store more products than required. By doing this EMS incur additional inventory storage costs but can avoid delays in delivering product when there is a surge in the demand

5.5 Factors Driving the EMS Market

The following are the factors that drive the Electronic Manufacturing Services

- **Cost advantages** – Cost reduction is the important driver in outsourcing manufacturing to low cost economies and it is believed that outsourcing yields an average 10 to 15% in

[60] Fabless-Foundry partnerships: Models and Analysis of Co-ordination issues by Aran Chatterjee, Dadi Gudmundsson, Raman K. Nurani, Sridhar Seshadri and J. George ShanthiKumar, IEEE Transaction

savings[61]. The fabless companies can avoid high capital investments in property, plant and equipments required for manufacturing and the OEM's can lower their workload by outsourcing low-margin activities such as procurement, PCB testing and final assembly.

- **Growth in consumer electronics and communication markets** – The demand for faster, lighter, cheaper and feature packed products with short life cycles in consumer electronic and communication markets is driving outsourcing so that the companies in these sectors can concentrate on front end activities.

- **Bargaining power** – EMS providers have a lot of suppliers for raw materials and electronic components and have built relationships in such a way that they can negotiate better pricing, quality materials even when the supply is short. These partnerships have helped EMS to reduce their raw material costs significantly and keep their profit margin more or less fixed.

- **Dynamic markets and innovative technologies** – The rapid changes in innovation have led the OEM's concentrate on R&D and differentiate their products in the market place. There is a strong need to outsource their manufacturing to a supplier that can shorten time-to-market and time-to-volume production without any sacrifice in quality.

- **Infrastructure support in emerging markets drives growth** – Countries in the emerging markets are investing heavily in infrastructures to attract domestic consumption and foreign investments. Upgrading their infrastructure can boost their economy. This trend is also witnessed in other industries such as automobile, medical, industrial etc.

5.6 Risks of De-coupling Design and Manufacturing

In semiconductor product development process, the design is sent back and forth from manufacturing to drive layout modifications, to minimize parasitics and to increase the yield. The identification of the best design for a particular manufacturing process is facilitated when the manufacturing plant is close to the design house. As time to market is critical companies seek to

[61] F&S report on Electronic Manufacturing Services, 2007

avoid any delays caused due to iterations. Intel, Samsung and other IDM's enjoy the benefit of having close interaction between design and manufacturing while fabless companies face significant challenges and risks in decoupling them.

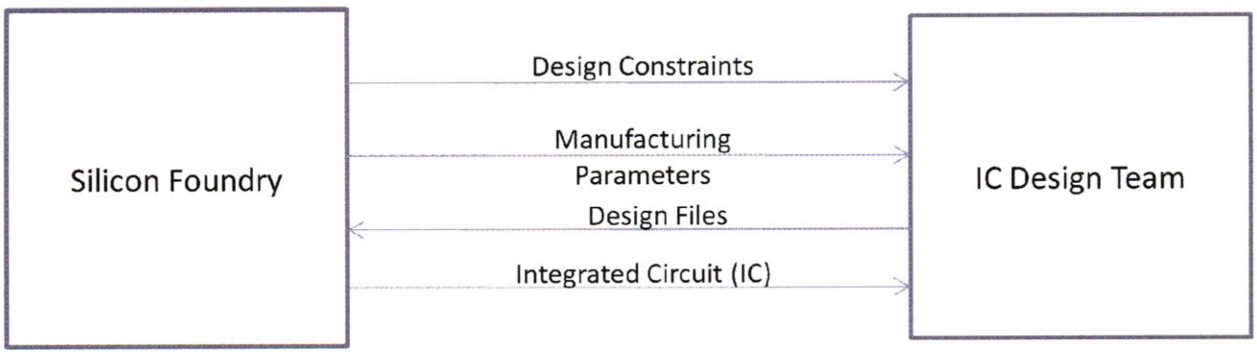


Figure 21: Interaction between the foundry team and the design team

Figure 21 shows the interaction between the foundry team and the IC design team.

Leachman and Hodges in their benchmarking study of wafer fabs conclude that, "While learning rates for defect density vary somewhat, rarely is a bad start overcome by subsequent rapid development. This observation underlines the critical importance of highly disciplined development activity, and of tight coupling between development and manufacturing."[62]

The following are the risks that fabless companies face in de-coupling the design and manufacturing

- 'One size fits all' approach is difficult to achieve. Complex ICs require advanced process technologies and increased co-ordination to find the best design for manufacturing. As geometries shrink, the interaction between design and process continues to rise.
- Fabless companies will have to incur high switching costs to change supplier and the process can increase the time-to-market.
- Highly dependent on whether foundries are able to provide the right access and the right technology.

[62] Fabless-Foundry partnerships: Models and Analysis of Co-ordination issues by Aran Chatterjee, Dadi Gudmundsson, Raman K. Nurani, Sridhar Seshadri and J. George ShanthiKumar, IEEE Transaction

5.7 Criticality of Yield

Effective yield management and process control systems help reduce manufacturing defects early on in the process and can have a direct impact on bottom-line profitability. This requires significant effort on the part of both fabless as well as foundry. Improving yield requires the collection and analysis of data from many different sources within a particular foundry to identify and resolve the sources of yield loss. Accurate yield analysis increases yield productivity, ensures quick response time to yield problems and reduces die loss.[63]

When new technology is introduced, the amount of data that needs to be collected in the modern foundry is a complicated process. The modern processes contain hundreds of steps and data collection and analysis that can take from few days to several weeks. Outsourcing manufacturing has added further complication as there would be delay in the information flow to the design team to make changes.

$$\text{Chip cost} = \frac{\text{cost of die} + \text{cost of die test} + \text{cost of packaging}}{\text{final yield number (good chips)}}$$

$$\text{cost of die} = \frac{\text{cost of wafer}}{\text{dies per wafer} \times \text{die yield}}$$

$$\text{dies per wafer} = \frac{\pi \times (\text{wafer diameter}/2)^2}{\text{die area}} - \frac{\pi \times \text{wafer diameter}}{\sqrt{2} \times \text{die area}}$$

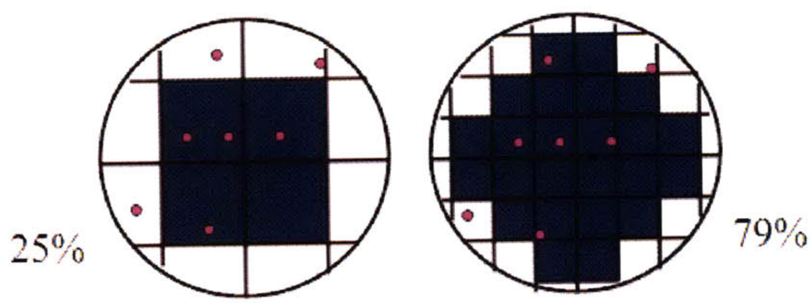


Figure 22: Yield Calculation

Figure 22 shows the formula for yield calculation. The cost of an integrated circuit is inversely proportional to the yield. i.e high yield would reduce the cost of chip.

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[63] Yield Analysis in the Semiconductor Industry – Business paper by Visual Numerics Inc, May 2002

5.8 Yield Management Solutions for Fabless Companies

Foundries work very closely with the design team to solve yield related issues. The yield analysts collect data from the foundry, analyze them and get quick feedback from the design teams to make changes in the process technology and vice versa. The merchant foundries that manufacture chips from many clients face major challenges during iterations. They heavily rely on tools that help fabless companies quickly make design changes in products without affecting the supply of devices. The softwares enable the fabless companies quickly implement design change orders based on quantitative trade-offs (Using Monte-Carlo Simulations) of various yield contributors. The fabless company then uses this data to maximize manufacturability of products in selected foundry processes before mass production starts.

"All IC makers are keenly aware that modifying IC designs to be compatible with the most advanced process and ramping to profitable yield quickly are critical issues. But for a fabless chip maker manufacturing a new IC design at a foundry, information vital to effectively integrate process and design is not readily available." ," noted John Kibarian, president and CEO of PDF[64].

5.9 Another Solution for Fabless Companies – Design For Manufacturability

The EDA companies have discovered solutions that have more significant impact on creating successful designs by reducing design errors as early as possible in the product development process. A product can be designed in many ways and the designer's objective should be to optimize the product design with the production system rather than designing a product that cannot be produced. The design methodology called Design For Manufacturability (DFM) includes a set of design instructions that design engineers should adhere for achieving high-yielding design for a particular process technology. DFM can be used to prevent the following issues that might result in low yield.

Figure 23 and 24 shows the DFM process and the guidelines.

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[64] http://www.eetimes.com/news/semi/showArticle.jhtml;jsessionid=R0SRF33O5SFSDQE1GHOSKHWATMY32JVN?articleID=10803169

- Chips designs that can simplify the assembly operations but require more complex and expensive components[65].
- Designs that simplify component manufacturing while complicating the manufacturing process.

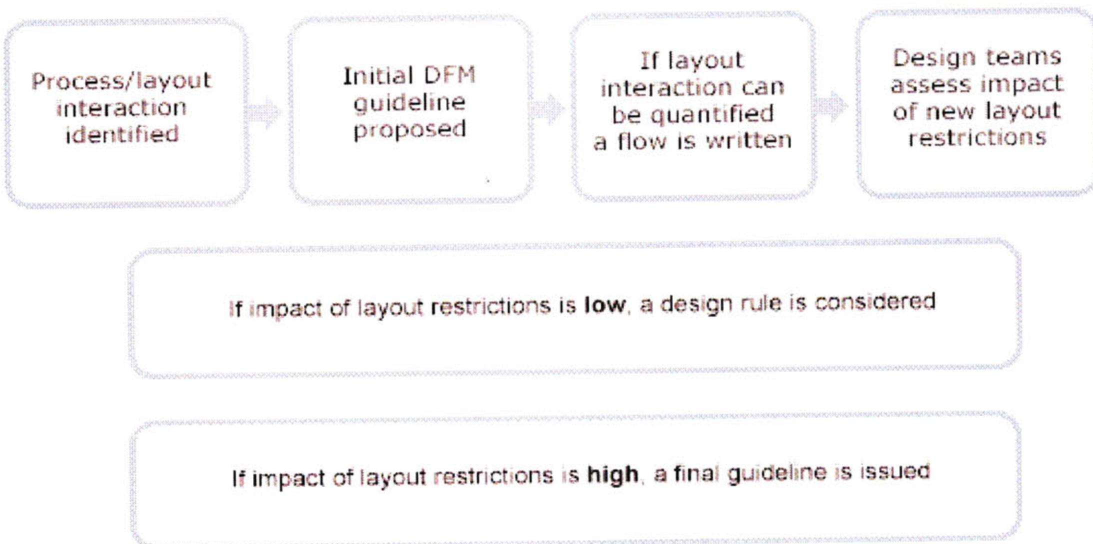

Figure 23: Intel's DFM Guides[66]

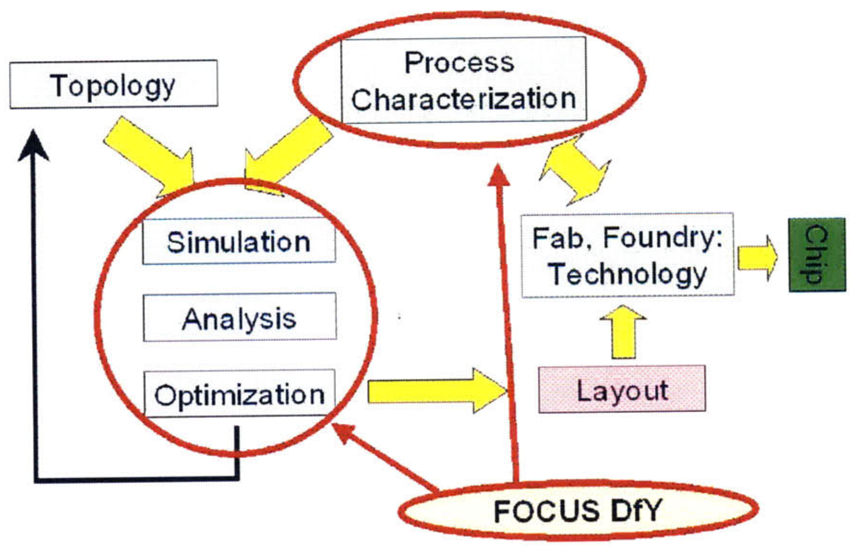

Figure 24: DFM Process

[65] http://en.wikipedia.org/wiki/Design_for_manufacturability
[66] http://www.intel.com/design/quality/pix/dfm_chart.gif

5.10 Competitive Advantage - Fabless (AMD) Vs Integrated Device Manufacturers (INTEL)

In this section, the competitive advantages of fabless companies versus companies that manufacture chips in-house are compared. Intel and AMD compete fiercely in the microprocessor market with leading-edge process technology and in late 2008 AMD went fabless to get economic advantage over Intel. AMD made a revolutionary move in the history of semiconductor manufacturing by spinning out their manufacturing division to Foundry Company, an investment company to reduce their long term debt that they had accumulated in the purchase of ATI technologies, a leading designer and supplier of graphics processing units and motherboard chips.

Jerry Sanders, the CEO of AMD who once said "Only real men have fabs", alluding to the advantages of owning a manufacturing plant in-house for close interaction with the design team, decided to transform his company into a leaner, meaner competitor against its more powerful rival Intel. The cost of operating and maintaining foundries was very high and when they are underutilized, companies are forced to sell foundries to third party manufacturers like TSMC or to an investment company. One of the questions that hang over the recent move to becoming a fabless company is the ability to stay competitive with Intel in the Microprocessor race. Although AMD is the only client of Foundry Company and can demand more traction from them now, whether the interaction would remain at the same level once the foundry company gets more clients is questionable.

Another big reason why AMD decided to opt for fabless strategy is because of the increase in the cost and complexity involved during the transition to a new semiconductor processing technology(see figure 25).

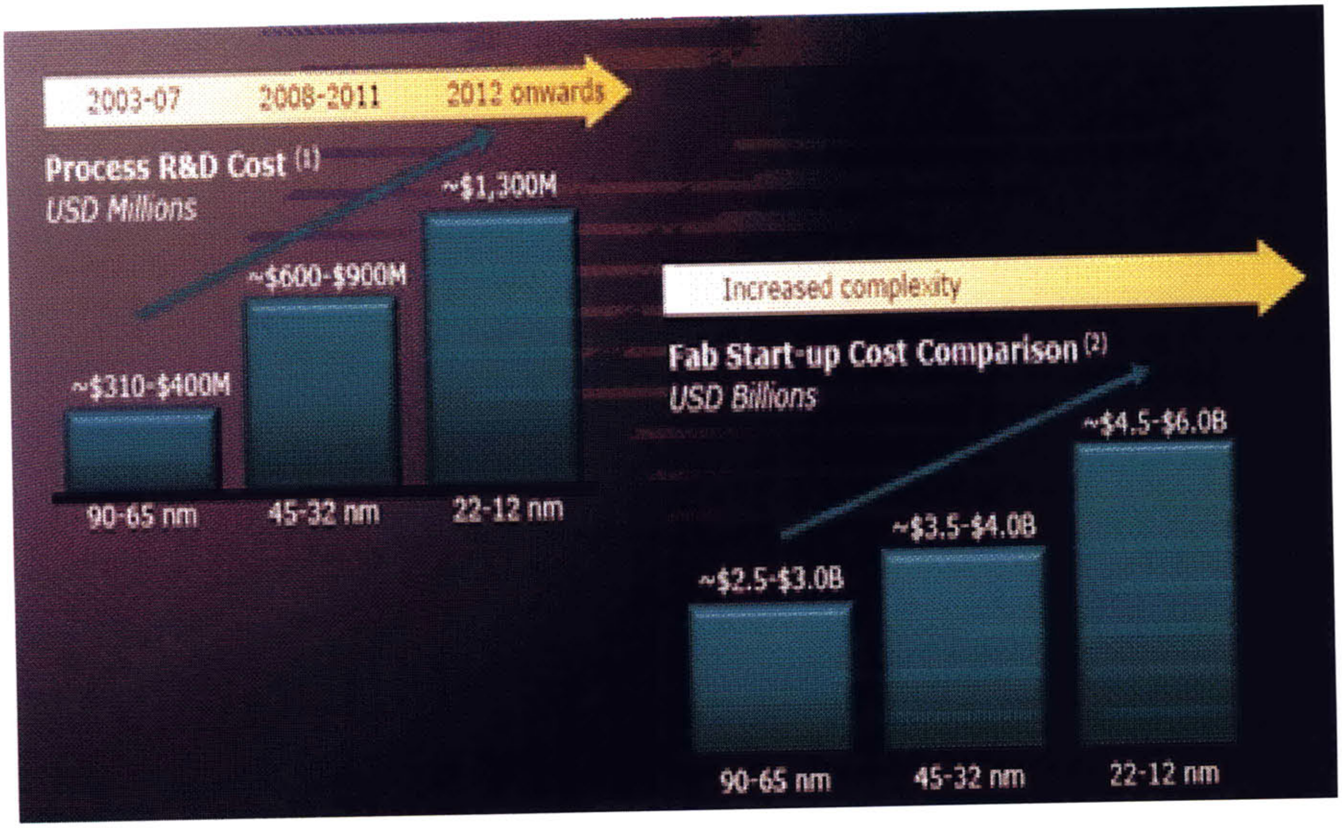

Figure 25: Cost and Complexity continues to rise[67]

Year	1997	1999	2001	2003	2005	2007	2008	2009	2010	2011	2013
Intel (nm)	250	180	130	90	65	45	45	32	32	22	16
AMD (nm)				90	90	90	65	65	45	32	

Table 6: Evolution of Process Technology at Intel and AMD

Table 6 shows the evolution of process technology at Intel and AMD

[67] AMD Financial Analyst 2008 ppt

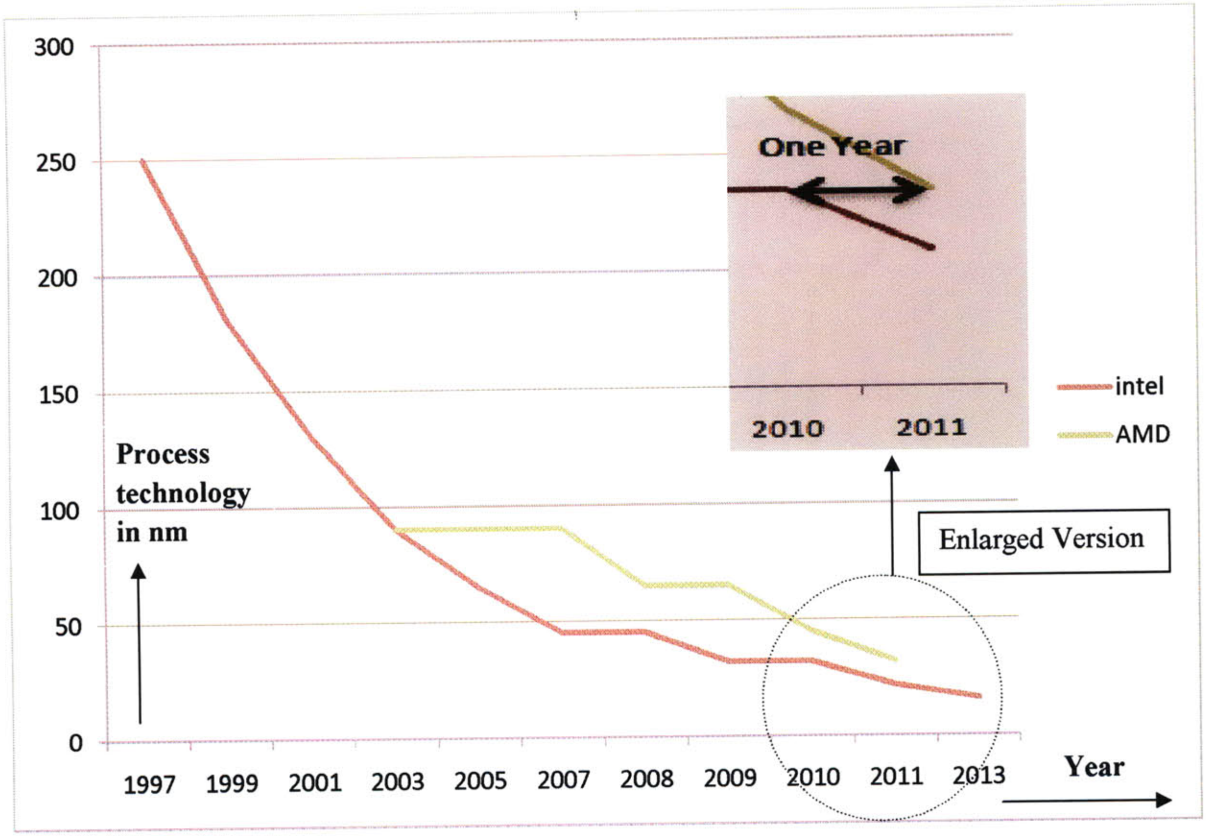

Figure 26: Intel Vs AMD Technology Chart

Figure 26 shows the technology comparison between Intel and AMD. AMD is lagging behind Intel in process capability by a year already and Intel is expected to lead this race with its foundry advantage. On the other hand, Intel has also outsourced one of their low margin and low volume processors, Atom processor to TSMC but manufactures its high volume, latest technology and core processors in its own facilities.

Intel's Advantages
Intel can expand their lead in process capability. Intel can invest heavily in upgrading their fabs during economic downturns.
Intel can lead in the event of price war as AMD is more vulnerable –similar to what happened to the makers of memory chips.
Tight coupling between the design and the manufacturing team and will

facilitate the reduction of time-to-market
Have control over the overall yield percentage
AMD's Advantages
Sharing of risk and expenses with Foundry Company.
Reduces involvement in manufacturing to focus on designing and selling chips.
Financially more stable as they need not invest heavily on the capital equipments

Table 7: Intel and AMD Advantages

5.11 Conclusion

Today's business climate in semiconductor industry has used outsourcing to help quickly and cost effectively enter a market. Electronic Manufacturing, which was once considered as a core competence by many chip companies, has now become a commodity due to advancements in upstream industries and companies have started adopting asset free strategy as their business model. Collaborative partnerships and change in the industry value chain are favoring companies to reduce their expensive capital asset base. Outsourcing model calls for high degree of co-ordination between the design and the manufacturing team to enhance and maximize strategic outcomes. In the old days, the design rules from the fabrication unit dictated the risk and if the design conforms to the rules, the yield is high. Today, products are out in the market within a short window due to market competitiveness and companies are either forced to use customizable logic chip that someone else had already designed to reduce the risk or find a new way to manage the risk. The fabless model perfectly works for companies (small and large) that develop products from an already existing customizable programmable logic and uses process technology that has pre-defined rules for manufacturing.

6 CHAPTER 6: CONCLUSION

6.1 Introduction

Companies in the semiconductor industry have adopted outsourcing to optimize their channel management capabilities and have derived significant business benefits out of it. The industry has undergone significant changes in the last two decades and outsourcing the manufacturing and research and development activities have turned out to be a successful business model. Due to changes in how the companies do business today, the players in the value chain have regrouped to build or strengthen capabilities that enable them to work more efficiently with channel partners on manufacturing and product design. Outsourcing model calls for high degree of co-ordination among the players to enhance and maximize strategic outcomes. The industry dynamics and pressures that semiconductor companies face today have made external capabilities absolutely critical for success.

6.2 Industry Transformation

The benefits of outsourcing include increased profits stemming from improved design-win success rates, early-to-market pricing premiums, lower SG&A costs due to shorter design and planning cycles and administrative overhead[68]. The industry is highly fragmented and outsourcing partnerships are not easy to develop. While helping companies cut costs and focus on core competencies, such fragmentation has led to an increasingly complex set of stakeholders and myriad of interactions that must take place among multiple, diverse organizations spread around the world[69]. Companies that outsource their activities have to be wary and flexible in how they handle and support these new breed of value chains.

[68] Achieving high-performance through superior channel management in the semiconductor value chain – Accenture's high tech solutions point of view. 2005

[69] Achieving high-performance through superior channel management in the semiconductor value chain – Accenture's high tech solutions point of view. 2005

Figure 27 shows the market shifts and the evolution of changes that have occurred in the semiconductor industry over the last three decades.

FROM	**TO**
Regional Dependence	Global Dependence
Supplier Push Operational Model	Customer Demand Operational Model
Influence of a single company	Influence of many companies
Market dominated by few companies	Fragmented market with many players and differentiated products
Price of Silicon	Value of Silicon – High Yield
Integrated Device Manufacturers with in-house foundries	Companies adopting fabless model
Limited support from EDA	Complete support from EDA, IP and EMS companies
Design based world	Front-end application driven products
Flexible time-to-market	Reduced time-to-market
Full design and verification services	Specialized design and verification services

Figure 27: Changes in the Semiconductor Industry

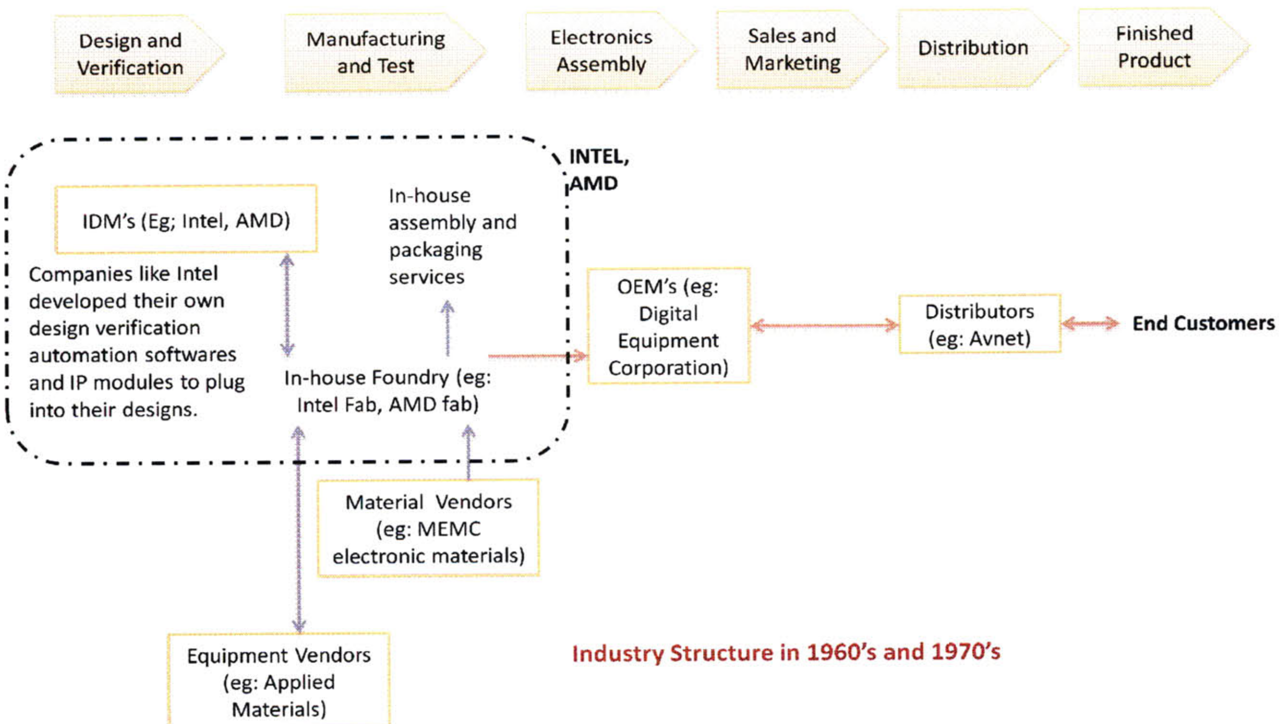

Figure 28: Industry Structure in 1960's and 1970's

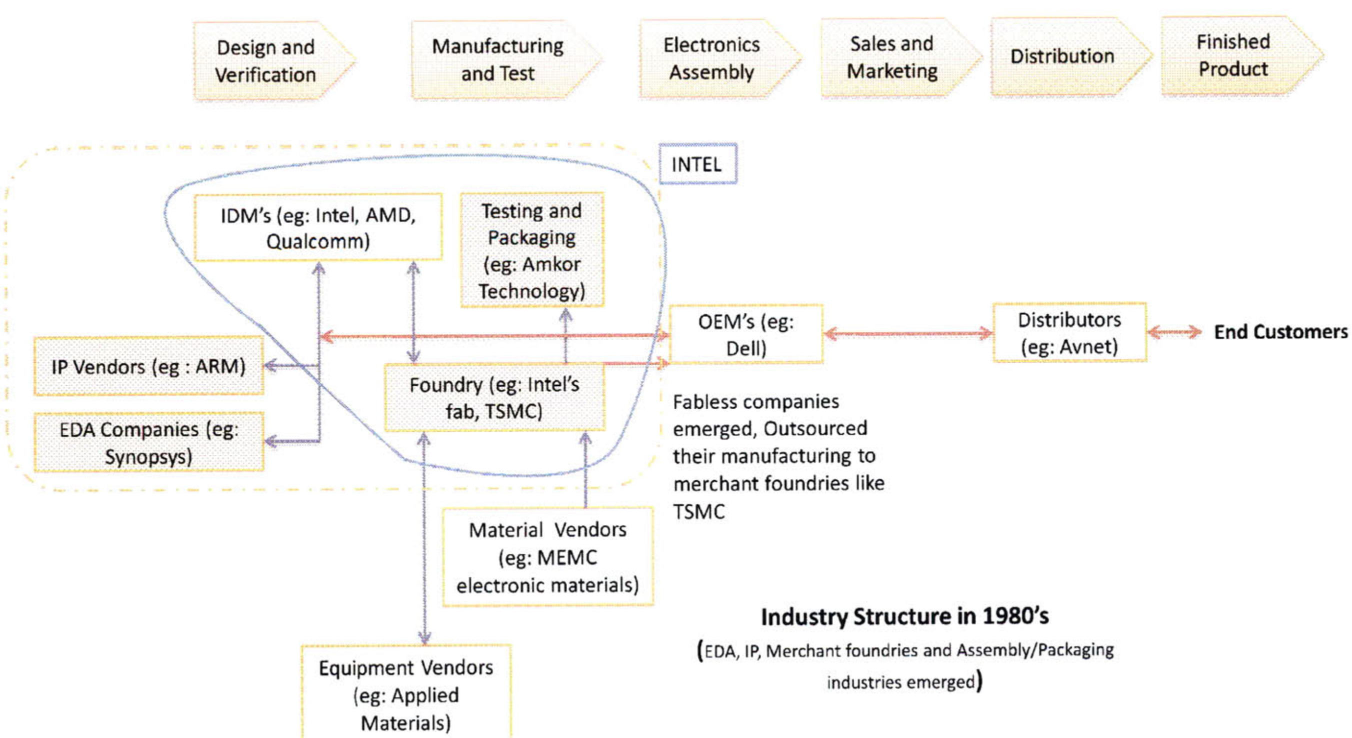

Figure 29: Industry Structure in 1980's

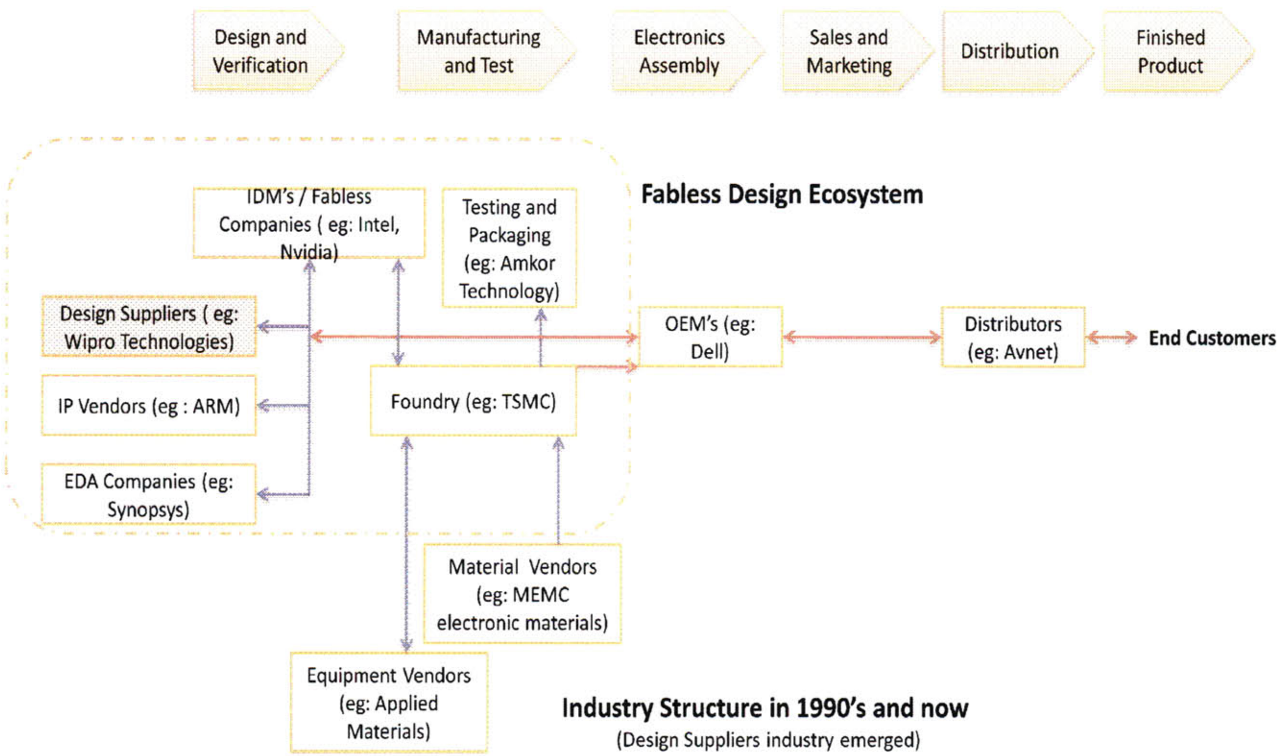

Figure 30: Industry Structure in 1990's and 2000's

Figure 28 shows the industry structure in the early 1960' and 1970's. During that period integrated device manufacturers like Intel and AMD had to develop their own simulation automation softwares to design and verify their chips. They used their in-house manufacturing units to manufacture the chips. Figure 29 shows the industry structure in the 1980's. The emergence of EDA, IP vendors, merchant foundries and assembly/packaging industries led to further decomposition of the value chain as IDM's started to license softwares and outsource manufacturing. Figure 30 shows the industry structure till date. The emergence of Design suppliers has led to design outsourcing and has spurred growth in the number of fabless companies (see figure 31).

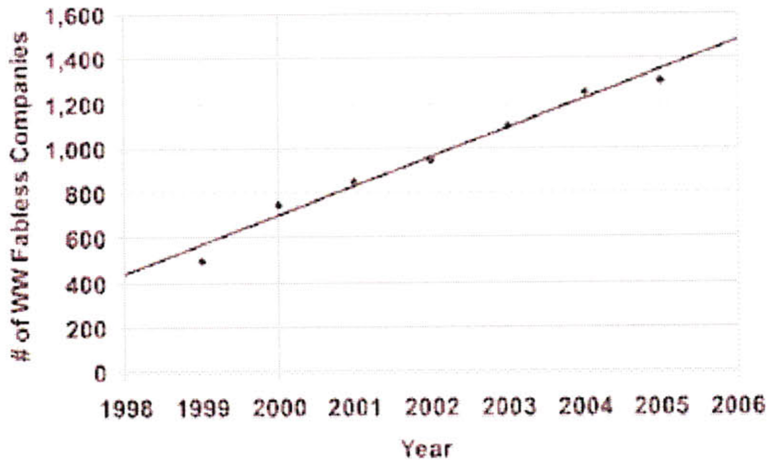

Figure 31: Growth in the number of fabless companies

Industry	**Timeline**	**Example**
IDM	Late 1960	1968 (Intel), 1968(AMD)
Equipment Vendors	Late 1960	1967 (Applied Materials
Material Vendors	1960	1960 (MEMC Electronic Materials
Merchant Foundries	Late 1980	TSMC (1987)
IP Vendors	Early 1980	ARM(1983)
EDA	Mid 1980	Synopsys(1986)
Design Suppliers	Mid 1990	Wipro VLSI (1995)

Table 8 : Industry Timelines

The market shifts and evolution of the value chain in the semiconductor companies have an enormous impact on their operations from design to manufacturing to customer service and support. Semiconductor companies have to be skilled at tracking all value chain activities to ensure quality and maximize their share of the value created – something that is difficult today due to fragmentation. This calls for high degree of integration among the companies in the value chain.

At a more granular level, since the market is consumer driven, semiconductor companies must understand customer needs and preferences far in advance of product development. In order to be successful in doing this, companies must align or have good relationship with OEM's to understand the various customer segments and behavior in each segment to define product-enabling technologies. Smaller and non-traditional channels are showing the way as technologies are adapting to consumer demands. By 2013, 50% of the semiconductors will be bought in use in consumer electronics, compared with approximately 40% today, according to research by Gartner[70].

Existing systems and distribution policies are strained by shifting focus to Asia. Global network dependence features continents, time zones, languages that separate engineering and purchasing teams, make communication and collaboration difficult[71]. As global relationships are established, the semiconductor companies are forced to explore new ways of rewarding design work versus solely concentrating in increasing their sales. When design is completed in North America and manufactured in Taiwan, companies have to establish global distribution channels breaking down their well established local channels.

With increased competition, increased design talent in Asia and strong need to reduce time to market and overall cost, companies are realizing the need for outsourcing design to third party design houses. A design activity that is geared towards developing a new product targeting an existing market using a familiar technology with incremental innovation can be easily outsourced. During this process, it is important for the companies to develop strong intellectual

[70] Garter Research, *"New Openings as Semiconductor Innovation Sets the Pace"*, Research Note, 07/31/03., Gartner Research, *"The Tidal Wave From Consumer Electronics Show"*, Research Note 02/25/04

[71] Achieving high-performance through superior channel management in the semiconductor value chain – Accenture's high tech solutions point of view. 2005

property and critical technical and human capital resources that can have a major impact on the direction in which specific product segments head.

Semiconductor manufacturing, which was once considered as core competence, is not a strategic differentiator anymore due to advancements in upstream industries. The Electronic design automation and EMS industries have discovered solutions that help fabless companies create successful designs by reducing design errors as early as possible in the product development process. Due to these advancement the fabless model has been very successful and perfectly works for companies (small and large) that develop products from an already existing customizable programmable logic and uses process technology that has pre-defined set of rules for manufacturing.

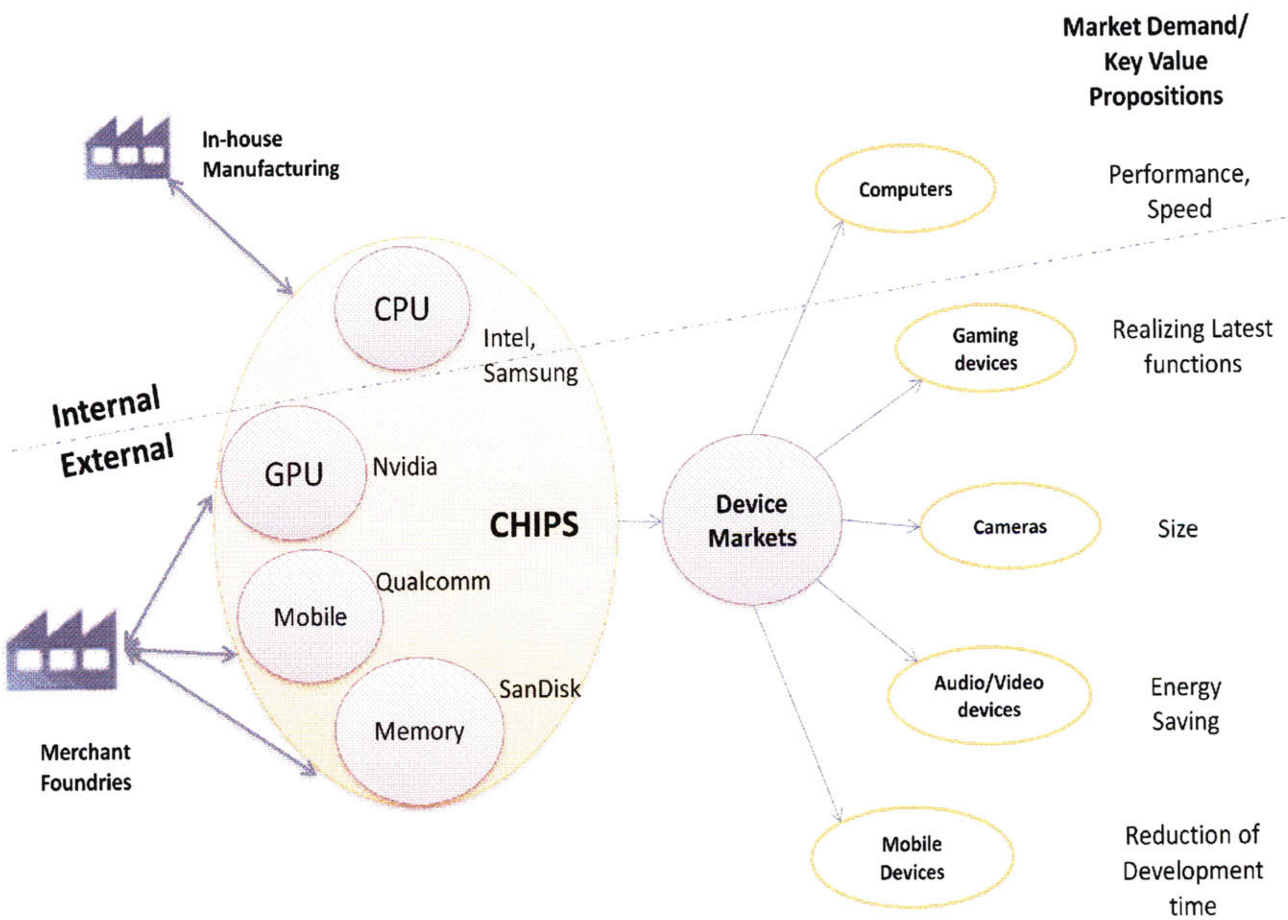

Figure 322: Trends in outsourcing based on key value propositions

Figure 32 shows the outsourcing patterns exhibited by companies based on key value propositions discussed in chapter 2. Companies that outsource manufacturing compete with other players in the same market in terms of features, size, energy saving and early go-to-market. The market does not require them to adopt the latest process technology. Hence these companies adhere to the pre-defined rules for design for manufacturability and outsource their manufacturing to merchant foundries. To capture first mover advantage these companies outsource their design to design suppliers who have sufficient talent and resource to shorten the product development time.

Companies that make devices competing on performance such as CPU require advanced process technologies that do not have pre-defined rules for design for manufacturability. Hence the companies manufacture such devices in-house to facilitate close interaction with the design team and to avoid delays and technology leakage.

6.3 Five Capabilities for Achieving High Performance in Fabless World

Optimized demand generation, leading edge design and high yield manufacturing, leadership in technical information, aggressive sales campaign and efficient supply chain visibility are the 5 capabilities for high performance in a fiercely competitive and uncertain business environment.

The first capability, optimized demand generation, involves the process of identifying the customers' needs, developing technical specification to meet those needs and creating awareness of the product. Achieving optimized demand generation requires identification and collaboration with OEM to focus on the targeted market.

Innovative design and high yield manufacturing is the second capability. Given the strong need for semiconductor companies to get to the market first, the company will have to leverage the existing capabilities in the value chain such as outsourcing to design suppliers, support from IP vendors and EDA, yield management from EMS and support from merchant foundries to deliver innovative technology solutions to end-customers. It is critical for the company to have a consistent and well-conceived process for identifying partners with which it will collaborate on specific products.

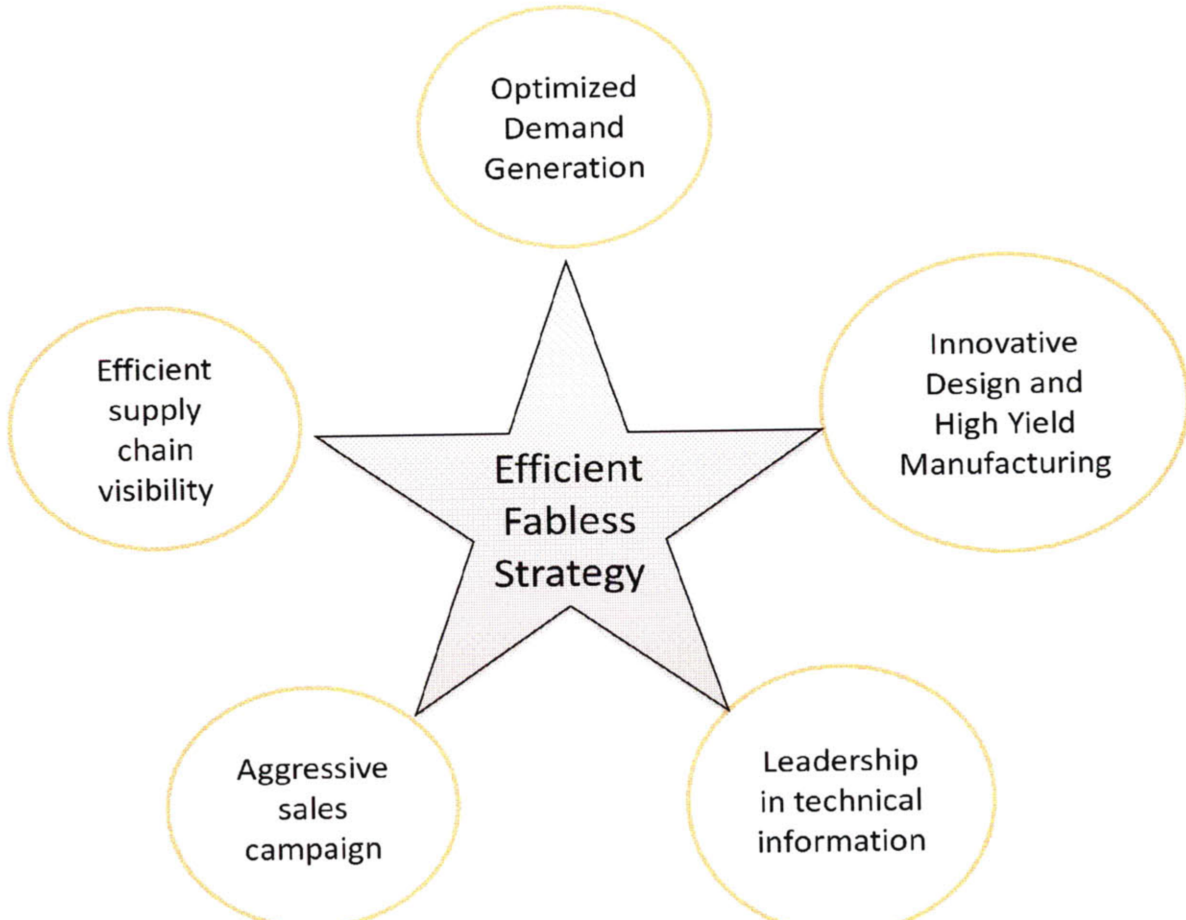

Figure 333: Efficient Strategy for Fabless Company

Leadership in technical information involving clear understanding of the intellectual property that serves as the point of differentiation in today's market place is the third capability. The semiconductor supplier must develop appropriate strategies for investing in product technology and market development, as well as for providing access to intellectual property and nurturing relationships among the customers that will be granted access[72]. The fourth capability is the development of efficient and aggressive go-to-market strategy that serves all customer segments with minimum redundancy. To ensure both direct and indirect customers are covered, companies must devise programs that provide technical support and resources globally in support of the sales objectives.

[72] Achieving high-performance through superior channel management in the semiconductor value chain – Accenture's high tech solutions point of view. 2005

The fifth capability is to create streamlined and efficient supply chain. This involves agreements between parties as to who takes more risk involved in inventory handling and storage. The companies should implement technologies that eliminate time and cost from supply chain while improving company's ability to address the needs of its high demanding customers.

6.4 Conclusion

Companies in the semiconductor industry should recognize the shifts in the market place and need to make changes in the own operations from design to sales to effectively respond to the industry dynamics and stay ahead of the competition. Awareness of specialized capabilities and strong relationship with players in the value chain would help sustain and generate strong business benefits.

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