Executive Advisory

Intel's Overlooked Advantage: A Case Study in Why Manufacturing Matters

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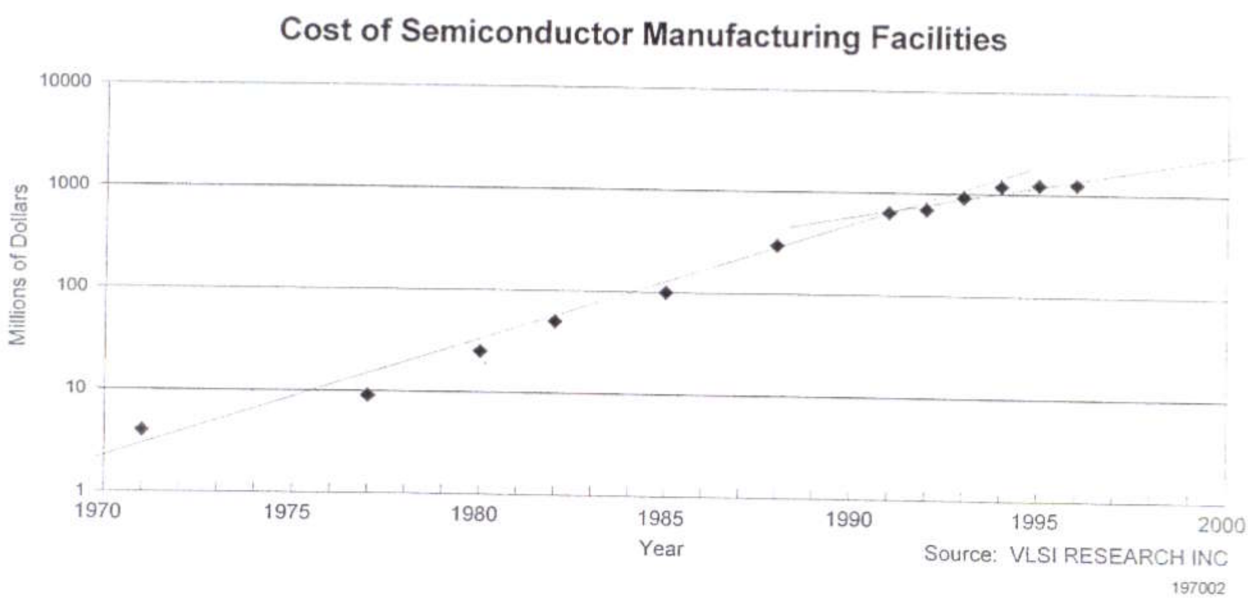
Please file in Appraisals 1997 behind Tab 9.

The computer chip industry is renowned worldwide for its ability to add ever more value to its products while continuously lowering prices. This ability comes at a high price, however, for industry leaders become embroiled in a perpetual technology race to excel in both chip design and chip fabrication. Indeed, in recent years the price of chip fabrication facilities—or 'wafer fabrication lines' as they are called by industry insiders—has risen unrelentlessly (see Presentation 1). Today, such fab lines, or 'fabs,' entail investments that frequently exceed one billion dollars per line. As these high costs have arisen, many smaller companies have banded together to purchase chips from larger firms. As such, they emphasized the design of the chips and became known as 'fabless' chip houses. Their suppliers gradually abandoned chip design, concentrating instead upon manufacturing. They became known as wafer foundries. The industry split in its opinions about whether a fab was even necessary. At one point, a well known industry leader summarized the issues with the parody: 'Real men have real fabs.'

But, do real chip companies have fabs? Does manufacturing matter? The questions have been a perennial topic in the chip industry since the first fabless companies emerged on the scene in the late eighties. Clearly, the easiest way to start a chip company is to do so without a fab. The one-billion dollar cost of a modern fab brings sticker shock to the faces of most chip executives. Yet, there must be some advantage to owning a fab. Otherwise, giant fabless chip manufacturers would exist, and at least one of the industry giants would have switched to being

Presentation 1



fabless by now. That has not happened. Instead, the larger chip manufacturers continue to emphasize ownership of wafer fab lines. Intel, the world's largest and most profitable supplier, has made manufacturing one of the cornerstones to its success. Intel's commitment can be witnessed in its upcoming appointment of Dr. Craig Barrett, drawn from manufacturing, to the position of president. Why do the largest companies continue to place high emphasis on fab ownership?

Probably the simplest answer to this question is that, at some point, someone must take responsibility for manufacturing, otherwise no products can be built, and no revenues can ensue. Those companies who choose to build fab lines do so because there are profits to be made. Consider for a moment two companies: one with a fab, the other without. Both companies compete against each other in the same market, with similar products. Assume that both are large enough to meet the economies of scale needed to justify a fab, and that they are equally efficient. The company with its own fab will experience lower costs than will the one without a fab. This is because the chip company who outsources must pay that foundry's profit margin as well as the cost of producing the wafer (see Presentation 2).

The fabless company will find that its alternatives discourage large size. For if the market is truly competitive, selling prices will be the same for both. Thus, the company using outsourcing will be less profitable than will be the more vertically integrated manufacturing company. Lower profits will mean lower stock valuations of the company, rendering it less able to attract the financial capital needed to compete. In the long run, the company with a fab will gain incremental market share because of its improved ability to invest. The fabless company can charge more for its products to maintain similar profit levels, but this will result in diminished market share.

Presentation 2

Cost Comparison: Fab versus Fabless

(Cost per wafer in dollars)

	Fab	Fabless
Wafer Manufacturing Cost	1500	1500
Foundry's Profit	-	300
Wafer Value	1500	1800
Test and Assembly	525	525
Cost of Goods Sold	2025	2325
Sales, general and administr	375	375
R&D	150	150
Total Cost	2550	2850

Source: VLSI Research Inc

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As a result, most fabless companies avoid mainstream markets and seek the smaller ones. They prefer niches which, being too small for the large manufacturers to supply, can offset their inherent cost disadvantages. Fabless companies can bring added value in these markets, needing only unique product designs. While this strategy can be very profitable, it ultimately limits their size.

Owning a fab offers more than just long term financial advantages. Companies with fabs can integrate manufacturing into an overall business strategy, using process technology to differentiate products and production control to better serve customers. It is far easier for a competitor to copy a design than to copy an integrated business strategy; this is because there are so many elements that must be copied successfully from the latter in order to be successful. Each element has a finite probability of success, which when combined, compounds to a very low probability of overall success.

Foundries must, by their very nature, limit process variation. This is to ensure stable processes, so they can produce a wide variety of designs with relatively high yields. This makes it possible to successfully supply a large number of fabless chip makers competing in widely disparate markets. Inversely, fabless semiconductor companies must match their designs to fit the process of their foundry. Using a 'plain vanilla' process technology results in 'plain vanilla' product performance, since the process with which a device is made is intimately tied to its electrical characteristics. Owning a fab gives a chip company the ability to tailor its processes to fit the necessary product characteristics. A chip company can choose processes and equipment which will give its products specific performance advantages. This is a key reason why some small chip suppliers like Altera, Maxim, Linear Technology, and Cypress Semiconductor own their own fabs. It is also an important reason for large semiconductor makers to have their own fabs.

Production control is another reason why manufacturing is important. In today's hotly contested electronics market, time-to-market is an essential competitive edge. Companies must carefully coordinate deliveries so that products are made without delay. An entire production line can be stalled if one chip fails to arrive. A recurrent nightmare for all electronics manufacturers is one in which product shipments must be halted because chips failed to arrive on time, or worse, they failed to function upon arrival. Next Computer attributed its failure to gain momentum, in part, to problems with ASIC (Application Specific Integrated Circuit) deliveries. Their initial set of chips failed to work as designed. After several redesigns and delays the product was introduced six months behind schedule. One cellular phone maker nearly failed to get to market on time because a design flaw was uncovered on the Friday night before the product launch. Their chip maker, having its own fab, was able to get them a new set of chips in one week's time, averting a potential market disaster. Delivering orders on time is becoming ever more important as chips are increasingly used in consumer products. Many a company has missed a great market opportunity because they failed to fill retailers' shelves for the Christmas season.

Having control over production can enable a chip company to fulfill a higher percentage of its delivery obligations. A semiconductor producer can use its fab to offer more complete sets of chips. Customers then have fewer vendors to manage, at the same time while gaining confidence that they can get to market faster than their competitors. Since suppliers who own fabs can offer advantages in delivery and electrical performance, customers can get to market faster with differentiated products.

About the only way that a fabless company can compete head-on with a fabbed company is to hope that the large, vertically integrated manufacturing company is less efficient and overburdened with overhead. Consequently, in the world of high-tech, where small companies constantly strive to topple giants, paranoia and fitness are the keys to survival. Large companies cannot afford the flab held by large, vertically integrated companies of the past. Each tier of integration must be as competitive as if it were a stand-alone business.

Intel's Transition from Follower to Leader

Intel's journey to the top provides an excellent example of how manufacturing is essential to becoming a leader in the chip market. Often depicted as the unassailable giant of the semiconductor industry, its success is casually written off as the result of IBM having chosen its 8088 microprocessor for the company's first PC. Intel's incredible ability to execute well is often overlooked, as is the fact that its road to success has actually been quite rocky.

In the early eighties, when IBM first began using the 8088 in its PC, the future looked dim for Intel. Microprocessors had never been a big part of the chip market, while more than half of Intel's revenues were being derived from memory. The market for memory was where the money was, and Intel had always been known as a leader in this important segment. Yet its prospects for holding that position were fading fast, as Japan's colossal electronics companies were making significant inroads into the memory market. Introduced in early 1981, Intel's version of the 64K bit DRAM (Dynamic Random Access Memory) was late to market. Worse, it had to be pulled from the market in the summer of that year, due to a design flaw. By 1982, Japan dominated the DRAM market.

Like most American companies at the time, Intel was woefully unprepared for Japan's onslaught. The leadership in manufacturing it had enjoyed in the seventies had eroded. When the chip market crashed in 1985, Japan responded by flooding the world's memory markets with product. Prices soon collapsed, uncovering Intel's weakness.

By the end of 1985, most American suppliers would be exiting the DRAM market and struggling to hold on to the EPROM (Electronically Programmable Read Only Memory) market. Many small companies were giving up manufacturing altogether, choosing instead to use foundries and rely on their design ability, using the newest sophisticated design tools becoming available. These tools put them on equal footing, in design capability, with large companies like Intel. At the time, there was excess capacity. Depreciation in chip factories is so high that most companies are quite willing to sell capacity at a loss in downturns. Thus, being fabless meant that the small companies could shop for a factory which was willing to lose the most. This made the fabless houses artificially low cost producers. Several such companies began development of a new microprocessor technology called RISC (Reduced Instruction Set Computer), which would be much faster than Intel's CISC (Complex Instruction Set Computer) technology incorporated in its x86 devices.

Meanwhile, Japan's behemoths were planning their next logical move: entering the logic chip market with microprocessor designs of their own. Their strategy was to promote a new operating system, developed in Japan, called TRON (The Real-time Operating system Nucleus). TRON was designed to make computers easier to use (very similar to Apple's Macintosh® and Microsoft's Windows® operating environments). They planned to produce TRON chips in their older memory factories, where available capacity was plentiful.

For Intel, 1985 would become a year that would mark the end of one era and the beginning of another. Intel was caught between Japan's ability to manufacture and the fabless chip suppliers' ability to design chips at low cost. Experiencing its first quarterly loss in fifteen years, the company's very survival was being questioned. Productivity[1] had stalled at a mere $64K per employee. Unlike the Japanese chip makers, Intel's attempts to offer foundry services from its excess capacity had failed—proving their weakness in manufacturing.

Intel recognized the need to change. The question was, In which direction? For lack of resources, Intel knew it could never copy the way Japan manufactured; nor could it duplicate Japan's culture in America. Intel believed it would be fruitless to follow the fabless suppliers because of Intel's size, so it set a new course.

At that time, the Intel 386™ microprocessor was about to be introduced. It would have about four MIPS (Millions of Instructions Per Second) of computing power—about as powerful as the mainframe computers ten years earlier. It was Intel's best bet for the future, if it could be manufactured efficiently and profitably. So Intel restructured management in August of 1985, just two months before the 386 was announced, naming Dr. Craig Barrett to head all manufacturing. Dr. Andrew Grove, then President, considered the position important enough to see that Dr. Barrett reported directly to him. Previously, manufacturing had been under the auspices of the components group.

Dr. Barrett immediately set out to "emphasize manufacturing discipline" and turn Intel's manufacturing around. His first goal was to double Intel's output, while trimming the list of existing factories. He shuttered those factories that were no longer productive, ending bipolar production and transforming Intel into a wholly CMOS (Complementary Metal Oxide Semiconductor) company in the process. No chip maker had ever before been successful in making such a transition. Barrett set his sights on improving productivity and sought to "tailor manufacturing more to the markets they served."

Dr. Barrett knew he had to increase productivity through his people, so he concentrated on raising job standards for manufacturing employees, instilling a greater sense of worth in them at the same time. There had traditionally been three job functions in Intel's fabs: equipment engineering, process engineering, and material movement. Dr. Barrett merged these tasks into a single function, giving production personnel more responsibility than they had ever had before. It required more capable, better trained, and better compensated employees who were willing to take on more responsibility, which in turn, made manufacturing a prestige job at Intel.

He made quality the byword at Intel, training all of its manufacturing employees in quality management techniques and statistical process control. He also proved to be a strict disciplinarian when it came to quality. He stopped Intel's inward looking practice of benchmarking its fabs against each other and insisted that they be measured against world's best manufacturing plants. Dr. Barrett became an evangelist for reducing contamination, which cause defects that can destroy chips. He is still known for his frequent tours of Intel's fabs, at times getting into and under equipment to look for dust. There were also major changes in the fabs Intel was building. New construction materials, such as ultra-clean piping for gases and chemicals, were incorporated into the design of the fabs. Construction methods were made cleaner.

Within two years, Intel's blight had been turned around. In 1987, revenues rose 50 percent and productivity was up almost 60 percent. By 1988, productivity was well over twice what it had been in 1985. Productivity gains became the cornerstone of Intel's turnaround (see Presentation 3). Most of these gains came from manufacturing alone, as revenue per manufacturing employee rose from $114,000 in 1985 to $461,000 in 1995. Revenue almost tripled during this period, while the total number of employees in manufacturing fell by 30 percent.

It was during this time that Dr. Barrett instituted Intel's 'copy exactly' manufacturing strategy, which would prove to be critically important to holding the microprocessor market. The duplication of factories was the underlying principle of 'copy exactly'. In the past, equipment and processes used in research were often quite different from those used in actual production. The transfer of new technologies into production was always poor as a result. Intel changed this by mandating that the equipment selected and the processes developed in research would be pro-

[1] As measured by revenue per employee.

duction worthy from the start. The performance capability noted in research would become the benchmark for manufacturing to perform against. Once a new technology was approved for production, equipment and processes would be copied exactly throughout Intel's manufacturing facilities. Its fabs were so nearly identical that partially processed wafers could be moved from one factory and completed in another. It was 'copy exactly' that convinced customers to use Intel as the sole source for the 386. In the past, chip companies had always been encouraged by electronics manufacturers to find backup suppliers who could provide second sources for their designs. They did this because chip makers were often unable to supply demand, and were prone to losing manufacturing processes. These same systems builders liked second sources, since two suppliers could be played against each other to keep prices down. However, such practices limited the development of the logic market, as it was impossible for chip makers to obtain much value from intellectual property. This limited the value of designs and held down profits, thus curtailing the development of the market. Intel was able to overcome this limitation because 'copy exactly' provided multiple factories that were more capable of second sourcing each other than any other company's factory. The risk of natural disasters was lowered by building fabs in several locations around the globe. Intel was able to convince customers they did not need a second source, which allowed the microprocessor market to develop into more than just the small niche it had been.

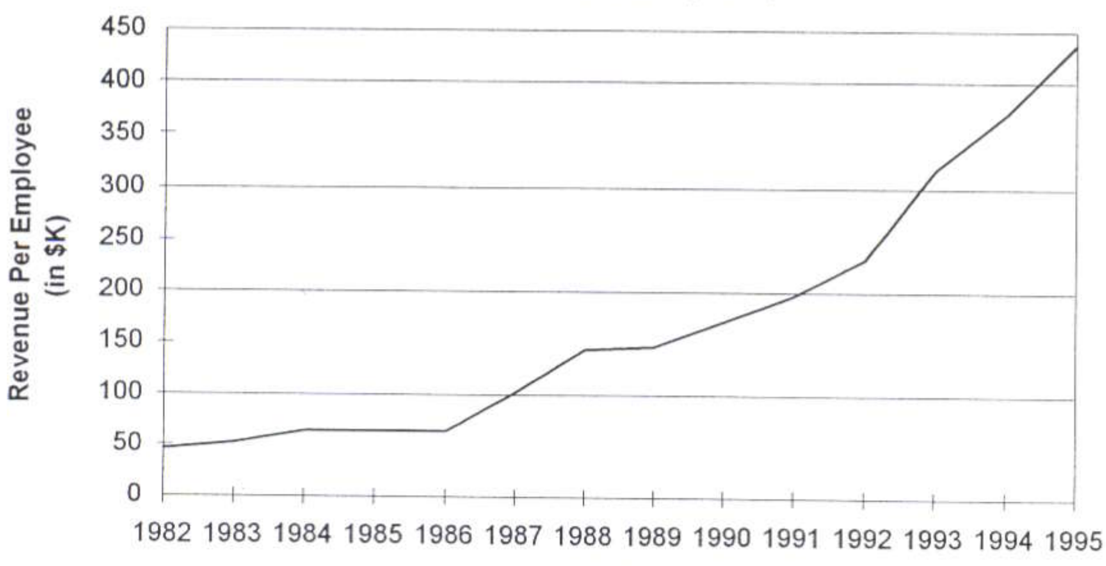
Intel's improvements in manufacturing led to significant advancements in the products it could offer. Chips became faster and could be made with more transistors. The performance gap with RISC began to close. When the Pentium® processor was introduced in 1993, its performance could match that of the average RISC chip. By 1995, with its newly introduced Pentium® Pro processor, Intel was able to match the performance of the best available RISC chips.

Manufacturing: The Foundation for Intel's Leadership in the Semiconductor Market

Each day, chip makers produce what is arguably the most complex product mankind has ever built, in volumes previously unmatched, from

Presentation 3

Intel's Productivity Ramp



Source: VLSI Research Inc

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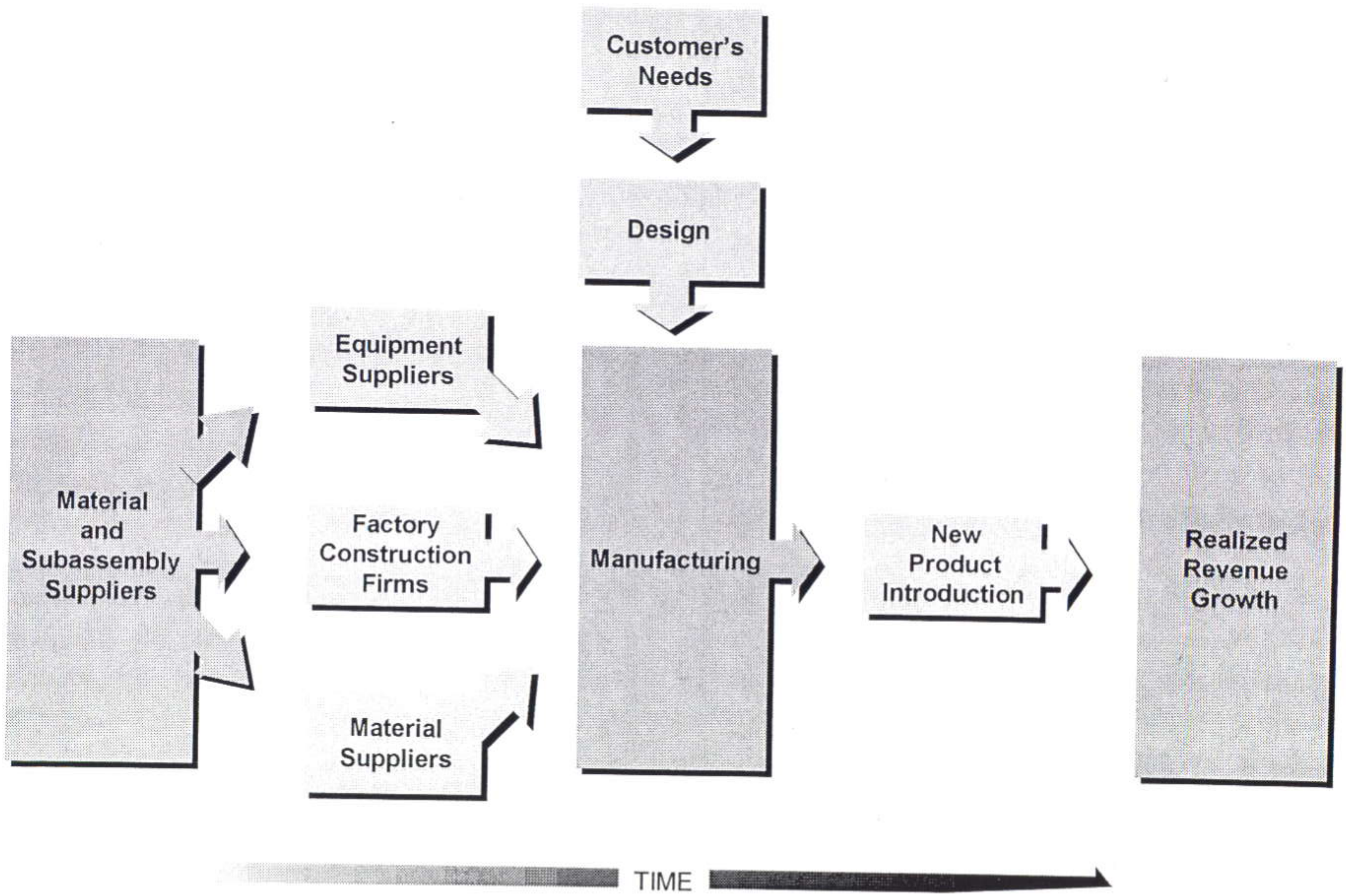
Manufacturing's Core Role in Business



factories more expensive than any in history. Staying at the leading edge under these conditions is extremely difficult. Companies compete on two fronts to bring out the best devices: design and manufacturing. Products are mad unique with design, while manufacturing makes them perform—each method is worthless without the other.

Manufacturing provides the foundation for Intel's position of leadership in the semiconductor industry. Intel is renowned for its ability to design and market leading edge microprocessors. But it is easy for other companies to do the same. AMD, DEC, IBM, MIPS, NEC, Sun, Cyrix, Hitachi, Motorola, Nexgen, Toshiba, Fujitsu, Mitsubishi, and many others have brought, and continue to bring, good products to market to compete with Intel. Intel's overlooked strategy for confronting these challenges has been to produce more chips, at the cutting edge of manufacturing, through better planning and execution.

Manufacturing, to Intel, is more than just making chips. It is an extensive planning and execution process, developed by Dr. Barrett, that is both tactical and strategic. It is tactical in the sense that day-to-day operations are extensively mapped out. All decisions are detail oriented, data driven, and then acted upon, with the results measured for future learning. It is strategic in the sense that it carefullroadmaps a series of market and technical routes to a finite product introduction point. The market roadmap defines precisely when customers will be ready to buy the next generation's product—if too early, customers will not be ready to buy, wanting more use out of their current systems; if too late, a market window opens for competitors to enter through. Intel must also define exactly how much better the next product must be to inspire people to purchase it.

In business, markets are lost, not won. Intel's ability to remain the world's leader is critically dependent on its ability to hit new product introduction points precisely. Dr. Barrett has put an infrastructure in place to ensure that all technology roadmaps converge at these introduction points (see Presentation 4). With each new device generation, there are many technology development programs to be planned. For most companies, this means the many things they must do to get the product to market: designing the product, building the factory, selecting and installing equipment, ramping production or contracting with a foundry to build the product for them. A company may be able to execute well, yet fail due to lack of support from its customers or if suppliers fail to support them. Dr. Barrett's ideas ensure that this type of failure occurs rarely, by having control over what happens in other parts of the food chain.

Unlike the large vertically integrated giants of the past, who sought control by owning every part of the food chain, Intel maintains control by supporting its customers and vendors. Intel understands that, with its size and influence, it can easily mess things up. It seeks to avoid this through partnering, constantly looking forward, ensuring that the world's many PC makers will have the technology needed to build its advanced products. The boards and systems its chips go into must keep up with the speed of its microprocessors.

Intel must also look backwards to ensure that its vendors, and even its vendors' vendors, will be able to provide it with the products needed to produce microprocessors in the volume required. Every piece of equipment used in the next generation's factory must be developed, tested and qualified for production. Each step in the production process will be developed in conjunction with equipment and material suppliers. When completed, each must work as specified and not conflict with other process steps. For example, too much stress in an oxide film could break the wires that connect transistors; similarly, too much heat during deposition could damage the sensitive junctions in transistors.

These suppliers must also have the capability to supply their products in volume. They cannot be one-off prototypes. The sheer size of the microprocessor market necessitates that Intel have the ability to quickly ramp production. In order to do so, it must quickly propagate new production technology throughout its factories around the world. This enables Intel to supply the world's demand for microprocessors before anyone else.

Dr. Barrett has also made sure that individuals throughout Intel's organization are empowered to break down road blocks. For example, last year one of Intel's employees discovered that there was a potential shortage of a special glass needed for equipment critical to Intel's next generation products. On further examination, that person found that the equipment vendor, unaware of Intel's system needs, had not ordered enough glass to build the number of systems needed. Intel's employee intervened with commitments to purchase enough equipment to encourage the vendor to order the glass. In contrast, a similar situation occurred in the mid-eighties and Intel reacted by criticizing the vendor in a public forum rather than by working together to solve the problem. It found that the price of not being proactive was paid in limited growth. In another example of employee empowerment, Intel is forming a consortium to develop a new lithography technology needed to print circuits in devices to be produced early in the next century. The technology, developed by researchers at AT&T Bell Labs and the National Labs, uses extreme ultra-violet (EUV) light to expose 0.1 micron lines. When funding was cut back, the program fell behind, putting its future in jeopardy. Intel's employees convinced management to start the EUV consortium with over $200M in funding. In the past, Intel would not have gotten involved, much less having taken a leadership position; instead it would have left long range technology development to other companies.

Summary and Conclusions

In summary, manufacturing does matter: Being a fab owner is fundamentally more cost effective and less restrictive than being fabless. Additionally, manufacturing can be made part of an integrated business strategy that is difficult for competitors to copy. A company that owns a fab can use its process capability to differentiate products and its control over production to better serve customers. Owning a fab can also give a company control over the technology needed to advance its products.

Dr. Barrett has shown that being competitive in manufacturing is essential to a company's success and that working closely with vendors and customers to keep development efforts in parallel ensures product launches that are successful. Moreover, staying on track with vendors helps the industry as a whole. This is because new manufacturing technology generations are, for the most part, generic to the industry as a whole. The chip industry needs to absorb new technology somewhat uniformly so that complementary chips used to build complete systems will be ready when the market needs them. Of course, this aids Intel's competitors. But Intel has the advantage of having learned to use the technology first, and is therefore able to ramp its production faster, guaranteeing that it stays in a leadership position. Being in the lead of a technology race does not ensure victory, only running fast enough to stay there does—which is what Intel does best.

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