Benchmarking with Product Life Cycle Analysis in the Semiconductor Industry

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A benchmarking of seven companies which manufacture specialized semiconductor devices such as highly customized analog/digital devices demonstrates that the differing role of information technology in these otherwise similar organizations is best understood by knowledge of how the company has positioned itself on the Product Life Cycle (PLC). The role of information technology changes markedly as a function of what strategy the firm adopts to address the rapidly changing demands of the semiconductor industry. Even though they are in the same sector, companies at the leading edge of the PLC do not need heavy emphasis on information technology, but companies which concentrate on more mature parts of the PLC have a corresponding heavier reliance on information technology. Benchmarking methodology can be extended by integration of the PLC, and this may prove useful in analysis of other economic sectors.

There are two types of semiconductor manufacturing companies: the 'merchant producer' and the 'custom house'. The merchant semiconductor manufacturers are easily recognizable: Nippon Electric Corporation, Hitachi, Toshiba, Texas Instruments, Intel, and Motorola. These companies have distinguished themselves by production in very high quantities — millions and tens-of-millions — of memory chips. They concentrate on large production volumes in order to quickly lower the cost per unit of the chip, for it is cost per unit as well as market entry timing which determines success in the marketplace. As a result of this need for high volume production, the chip being produced is usually designed for use in the widest possible range of products; both consumer and military.

The 'custom house' specialized semiconductor industry is entirely different. Instead of lot sizes in the millions, production volumes are many times measured only in the thousands, or tens of thousands. Instead of chips which have relatively simple designs, but which nevertheless are highly compact; these 'custom houses' tend to produce highly complex chips.[1] Instead of attempting to design general chips which have the widest possible range of uses, the custom houses design chips which are individually tailored, many times for a only single application, such as the guidance system on a missile. In addition, the general design process is very different. A great premium is placed on working with the customer and co-designing the chip according to unique specifications. Highly profitable systems integration work generally accompanies the creation of a specialized semiconductor product.

At the same time, there is an unwritten "law of similarities" in information systems. It holds that companies operating in the same economic sector and producing the same products should utilize roughly equivalent information systems in order

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to go about their work. Although there are variations from firm to firm, in the broader context, similar firms are expected to have roughly similar information systems. Most airline companies operate a reservations system, UPS and FedEx have similar logistical problems which are handled by roughly equivalent information systems and all banks participate in a clearing house, etc.. Even when the researcher finds differences between two companies engaged in the same line of business, these variations are far less than those found between businesses operating in completely different sectors. For example, regardless of their differences, the information systems in two banks have much more in common with each other than they have with a car manufacturer, or any company in a different sector.

In contrast to the "law of similarities", product lifecycle (PLC) theory holds that development and manufacturing of goods goes through a series of identifiable stages and suggests that even when firms are in the same line of business, they can focus their operations so as to approach each stage differently, and that when they do, the nature of their internal processes change. It is only a short extension of logic to suggest that as a result, their information processing must change as well even if they are in the same sector.

This raises the question of whether we can identify significant differences in how otherwise similar firms use information technology and if so, then can these differences be accounted for by how the firm approaches the product life cycle?

If this were the case, then PLC analysis might provide a useful tool for business enterprises as they plan their deployment of information systems.

This paper first discusses PLC theory then suggests how it might be applied to understand how information technology is used in firms. It then reviews a benchmarking study done with seven companies in the specialized semiconductor industry. It concludes that PLC theory can be used to explain differences between how otherwise similar firms use information technology. It also indicates that use of benchmarking can be improved by incorporation of PLC effects.

Background

Product life cycle (PLC) theory holds that products go through different phases and this drives firm strategy (Forster, 1986). There is an initial phase when the product is being introduced to the market, a period of rapid growth in the demand for the product as it builds market share, a period of maturity when the successful product reaches long production runs, and then a final stage when the product declines in its sales level and either stabilizes or fades away altogether from the market (Jewkes et al, 1958; Wells, 1972; Barrow, 1993; Mangelsdorf 1994a,b,c,d). This product life cycle ensures market penetration levels follow the S-curve pattern (Modix, 1994), around which firms generate their marketing strategies (Robertson, 1993; Slater, 1993).

In high technology, the PLC is a critical factor. Although many products have very long product life cycles (Mercer, 1993; Rifkin, 1994), those of consumer goods and electronics are considerably shorter. For example, Microsoft has a PLC of only 12 to 18 months for visual basic (Fawcette, 1994). In some cases, smaller producers target their production as a function of the anticipated PLC of a large company, as seen with Quarterdeck Office Systems following Microsoft (Paley, 1994). Product cycles in the personal computer industry have shrunk to four months (Goldberg, 1994), and computer generations in stores have now shrunk to only 6-12 months (Connors, 1994).

PLC analysis has also been linked to consumer buying behavior (Brannon, 1993), and as a result companies have demonstrated success when sales training for consumers is driven by PLC analysis (Kortge, 1993, 1994). For example, those with out-dated or "mature" equipment find it useful to develop sales strategies to attempt to prolong their product life cycle (Ruess, 1994). The shrinking PLCs place strain on consumers who must make purchasing decisions under conditions of rapidly falling price performance curves for computer equipment (Kessler, 1994), and force some to treat much expensive equipment as "disposable" (Foundyller, 1993). Eden (1993) argues that collapsing PLCs mean consumers should urgently invest in new technologies. Fishman (1993) even argues that planned obsolescence and rapidly deteriorating products are preferable as they help to maintain innovation!

Griffin (1993) argues that in order to compete, firms must constantly monitor a cycle-time performance baseline to continually shorten their product development cycles. Young (1994) points out that Japanese manufacturers have adopted the strategy of *kaisan* in which product life cycles in consumer goods, particularly consumer electronics, are radically shortened by product "churning", the generation of quick variations in product lines.[2] In addition, the Japanese are reported to use product life cycle based "target costing" as a means to improve their relative price performance (Lee, 1994).

In semiconductor manufacturing, PLC analysis also plays a critical role. Many Silicon Valley firms tend to concentrate their business on the early stage of the product life cycle (Hobday, 1994). Mody (1987) reports that rapid market entry timing and accellerated learning speeds are responsible for Japanese success penetrating microelectronics markets dominated by shorter product life cycles. As a result, all specialist semiconductor manufacturers have moved to competition based on shorter production runs and faster turnaround, processes which are dependent in part on computer-aided manufacturing (Rayner, 1989). These product life cycle effects are even evident downstream as shown by the recent introduction of the Pentium chip which exposed Compaq to criticism it did not anticipate the next product life cycle in microprocessors[3] (Brandt, 1993).

That the relevance of how the competiveness of a semiconductor manufacturer is changed by its position on the product life cycle learning curve is indicated in the conclusions to the Sloan Foundation-sponsored Competitive Semiconductor Manufacturing Program:

> "These fabs with initially high defect densities are unable to overtake the leaders for several years, even when they achieve a rate of reduction in defect density twice that of leaders. ... differences in the management of new process introductions contribute significantly to the disparity in *early life yields*." [emphasis added]

If information technology (IT) is integral to the manufacturing process, and if that process and firm organization supporting it varies along the product life cycle, then PLC theory should have implications for managing deployment of IT in a firm.

Methodology

Benchmarking is a technique of making comparisions between firms. It relies on a variety of criteria, and uses both empirical and other types of information as the basis of comparison. The techniques of benchmarking change depending on the type of problem being studied, the purpose of the benchmarking exercise, and the level of generality being addressed. Some of the most effective benchmarking exercises involve comparisions between tightly-defined performance measurements taken of world-class firms. Benchmarking is used in a variety of fields for a large number of problems (Watson, 1993).

A review of reported benchmarking exercises over the past few years shows that benchmarking is both applicable to a large variety of business problems and business sectors, and is flexible as a methodology, as seen by the variance in reported steps from a high of ten (the Xerox methodology) to a low of four. See Table 1.

Benchmarking is a rigorous methodology because it focuses on meaningful performance measurements, it generally collects a wide-scope of information, rather than a very narrow-band set of information such as through an operations survey, and allows for an iterative process of investigation, mostly through multiple-sets of interviews. For this reason, benchmarking can not be effectively carried out without a substantial degree of management support.

There are several advantages to using benchmarking when comparing a small set of companies. Its iterative and wide-scope nature aid in the creation of meta-level generalizations which can guide subsequent research. It can help avoid misleading conclusions based solely on narrowly defined quantitative data. The flexibility of the method also allows the researchers to accommodate mid-project changes as new information is gathered and new insights garnered. It is a methodology which has been successfully employed on a wide variety of problems in management. Although benchmarking usually focuses on tightly defined performance measures, it is also used for rigorous qualitative analyses.

As seen from Table 2, there are three streams of benchmarking in the IT area: Type A involves analysis of a large number of companies according to a general set of statistical data, such as MIS budget expenditures; Type B involves benchmarking of a handful of companies according to detailed performance measurements, such as response time and customer or end-user support levels; Type C involves benchmarking of highly technical performance measures of computer equipment, either entire systems, sub-systems, or individual components, such as hard-disks or workstations.

The method adopted in this study was Type B, as it involved a limited (seven) number of companies and the study of a variety of qualitative as well as quantitative factors.

For this study of the family of specialized semiconductor manufacturers we chose a specific group: producers of analog-digital devices. Since the research was supported by Burr-Brown, a strategic management team from that company helped in selecting the targets. The companies selected for study were Burr-Brown's leading competitors. This type of criteria is frequently used in Type B benchmarking. The companies included in the benchmarking were Burr-Brown, Crystal Semiconductor, ComLinear, Maxim, Analog Devices, Precision Monolithics, Linear Technology — seven companies in all. Taken together, these companies are the top competitors world-wide in the design and manufacture of these highly-specialized devices.

Reference	Function and Industry	Process Steps
Baker, 1994/1995	Electronics manufacturing	4
Nelson, 1994	Electrical machinery manufacturing	10 (Xerox method)
Fitz-enz, 1993	Total Quality Management (TQM)	4
Weisendanger, 1993	Computer manufacturing compared to other industries	4
Camp, 1993	Xerox method	10
Landry, 1993	Quality control	4
Anonmyous, 1993	Procurement and logistics in aluminum production	6
Young, 1993	International manufacturing	4

Table 1: Applicability and Flexibility of Benchmarking as a Methodology

References	Description of Benchmarking and Type (A,B or C)††
Criner, 1994	Data quality management in the U.S. Defense Information Systems Agency.(B)
Moad, 1994	Re-engineering of MIS with IBM Consulting Group.(A)
Carbone, 1993	Electronic data exchange for the purchasing function in the electronics sector.(B)
Ernst & Young, 1993	MIS budgets and cost-effectiveness of operations in minicomputer installations.(A)
Betts, 1992	Texas Instruments and Champion International Corporation. Benchmark of data center costs, help desk operations, and management of computer uptime.(B)
Hepburn, 1992	Use of "dual simultaneous analysis" benchmarking technique to analyze performance of data transmission internetworking devices such as bridges and routers.(C)
Eckerson, 1991	Network management for wide area networks, premise voice networks, premise data networks and international networks.(C)
Eyrich, 1991	Review of IBM AS/400 benchmarking project which won the Malcolm Baldridge National Quality Award.(B)
Allen, 1989	Workload measurements in the mainframe environment, especially MIPS.(C)

†† For discussion of Types, see text.

Table 2: Reports of Recent IT Benchmarking Exercises

This family of companies is involved in production of analog-digital converters (A/D), a widely-used chip which takes analog information and converts it to digital or vice-versa. For example, in CD players, an A/D converter takes the laser-scanned information from the disk and converts it to analog signals for amplification. Another device might take temperature information and convert it into digital form for interpretation by a computer. A/D converters are one of the most widely-used, but least known, type of semiconductor in the world. The creation of many A/D converters involves their merging with highly specialized circuits, even the creation of hybrid semiconductor devices. The specifications for this type of semiconductor are generally derived from very close coordination with the customer. For most companies, no single customer or product accounts for more than 2%-3% of sales.

The companies studied are highly variable in their size, strategy, history and use of information technology. Some are rapidly growing start-ups, others have been in the semiconductor business since its beginning in the days of Philby and Noyce.

Analog Devices

Analog Devices is the largest of the companies studied. It was founded in 1965 by Ray Stata and Matt Lorser, graduates of MIT. It now employees 5,200 people worldwide[4] with 2,700 in Massachusetts where it is based. In addition to making specialized semiconductors, AD makes a wide range of products. It is one of the world's leaders in product innovation, and operates with a well-defined set of strategic 5-year plans. AD has concentrated heavily on customer relations and has developed four programs to carry out its mission: Customer Ordering System; Manufacturing Excellence Through Quality Improvement Process Programs; Customer partnership Program; and other programs to address the need of recruiting and training high quality engineering talent. AD focuses both on high performance/high price chips but also on high volume/low price chips.

Investments in information technology are aided through a Central I.S. Steering Committee. AD views all of the information systems as ideally working together in an integrated fashion and creating competitive advantage by helping with on-time delivery, reducing defects in manufacturing (statistical process control) and by reducing the averge order cycle time for products wanted by the customer.

Burr Brown

Burr Brown produces a narrower product range than Analog Devices, but has several unique processes for manufacturing which keep it out front in the fabrication of specialized semiconductors, including its ability to adjust circuitry at the microelectronic level using lasers. BB was founded by Paige Burr and Tom Brown in 1956 in Tucson, Arizona. By 1959 it was manufacturing transistorized component parts known as operation amplifiers which aided in ranger missle experiments on the moon. Approximately 70% of BB's sales are international, and it has manufacturing and technical facilities in Livingston, Scotland and Atsugi, Japan in addition to headquarters in Tucson, Arizona. Its sales have risen from \$12m to \$180m from 1975 to 1989. It makes a very broad range of products from precision integrated circuits; modular electronic power supplies; data entry and display terminals; microcomputer input/output systems; instrumentation systems; and LAN limited distance modems.

ComLinear

Comlinear specializes in the design and manufacture of high-performance analog signal processing components. More than 60% of its sales are to the military, and it has a sophisticated statistical quality control program in place to keep its "1772 certification" for high-level defense contracts. In 1989, its sales reached \$16m. It is a small and generally secretive firm with a strong corporate culture. Most of its products are produced in small batches of 1,000 to 10,000 units, confirming its positioning in the specialized semiconductor field.

Crystal Semiconductor

Crystal is a fast growing, aggressive start-up company based in Austin, Texas. Crystal was small when we studied it, and was aiming to provide highly customized, high performance circuits for companies which could not be served by the larger semiconductor manufacturers. Crystal attempts to engineer its products to last much longer than those of other companies. It had only 125 employees (growing rapidly), but was working hard on developing an information system which would remain totally integrated regardless of how large the firm grew in the future. This strategy has apparently worked. (See below.)

Linear Technology

LT's 400% growth rate over the past 5 years prior to the study was based on their ability to customize products and provide a high level of on-time delivery of product. LT both designs and manufactures its products, and appears similar in some respects to Burr Brown. It spends a minimum amount of resources on information technology out of its $64m sales. Its mission is to be the world's leader in the design, manufacturing and marketing of linear integrated circuits.

Maxim Integrated

Maxim has concentrated on being a broad line supplier in the rapidly growing mixed-signal CMOS market. Its 1989 sales were approximately $55m. In addition to providing design and manufacturing for customized semiconductors, Maxim also acts as a second sourcer for various components which are in short supply. Interviews indicate that Maxim has a reputation of being able to deliver on time for orders which have been placed.

Precision Monolithics

PMI is a smaller specialized company which manufacturers advanced, standard, and custom monolithic linear integrated circuits; including switches/multiplexers; line-interface units; matched transistors; voltage followers/buffers, references, and comparators; analog-to-digital and digital-to-analog converters; and sample and hold, instrumentation and operational amplifiers. Sales in 1989 were approximately $90m, with 50% going into the military. PMI concentrates on producing well-established products, and uses information technology to maximize the efficiency of its manufacturing processes.

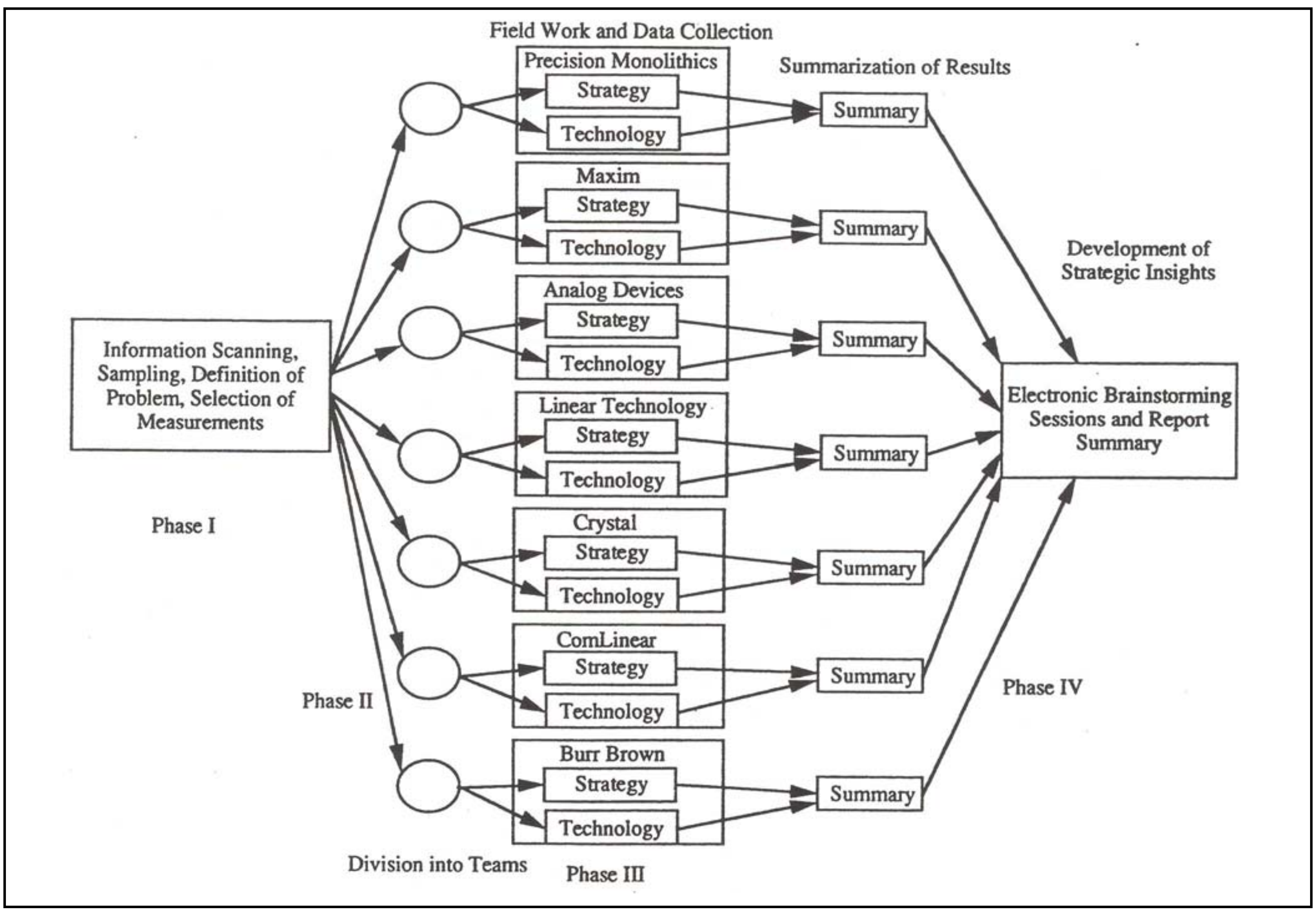

Figure 1: Phases of the Benchmarking Exercise

Benchmarking usually takes a year or more. In this case, initial data collection was done in the spring of 1992, and involved approximately 75 persons divided into 7 major teams, in addition to the many persons who helped in the interviews and provided management and logistics for the project.[5] See Figure 1.

The project followed a four-phase benchmarking method: (1) Phase I — Information Scanning and Structuring of the Problem; (2) Phase II — Business and Technological Analysis of Each Company; (3) Phase III — Sub-Team, Team, and Group Summaries; (4) Phase IV — Strategic Analysis.

During the first and last phases of the project, this large group worked as a whole. However, during the middle parts of the project, the group was divided up into teams: roughly 10 persons per company team, and roughly 5 persons on the business and 5 persons on the information technology sub-teams. (See below.)

During Phase I, the group as a whole went through an accelerated learning curve regarding competition in the semiconductor industry. Two tours of semiconductor manufacturing facilities were arranged. Also, a wide-ranging selection of industry studies were handed out and discussed, e.g. Okimoto et al (1987). After this general information was collected, the group worked together to create a general structure of the problem. This type of rapid environmental scanning and assimilation of a wide variety of information is typical for the early phase of a benchmarking exercise.

Given the type of industry being studied, we sought to examine the strategic role of information technology, and how it relates to the organization of the semiconductor company. Generally, one would question the validity of relying on any single quantitative measurement to assess IT in a firm, so in order to determine this relative importance, the teams collected a series of contextual data points. The data was designed to show the relationship with firm structure and also to determine how the firm relates to the PLC in its manufacturing activities. Given the highly competitive nature of the semiconductor industry, it was quickly discovered that firms are generally well aware of product life cycles and their strategy for fitting into them.

In Phase II, the group was divided up into 7 teams — one team for each of the companies being studied. Each team was further divided up into two sub-teams; one to study the general business strategy, the other to study the use of information technology. Each person was given a specific piece of the problem. The sub-teams were concerned with compiling and assessing the overall strategic mission of the company, the general corporate strategy, the competitive structure of the industry, the nature of sales and customer service, which we had determined was a leading indicator of competitive success, the organization of operations, engineering organization, the information systems budget and how it is controlled and the future prospects and strategy of the corporation.

After the team assignments were made, each team went through a process of determining the sequence of analysis to use, determining the major questions which needed answering; assigning team members to each of the relevant portions of the problem; coordinating the research effort (since the number of contacts made with each of the companies being studied had to be carefully controlled so as to not dry up sources of information); and swapping of information.

As mentioned, benchmarking is a wide-scope flexible methodolgy for firm comparison, particularly in terms of the types of "permissible" information which can be used. Within that context the teams began to analyze and collect data from a variety of sources including: personal and telephone interviews with the companies, scanning and study of publication information and data on the company (credit reports; annual reports; articles; product brochures, catalogues, etc.), review of materials which summarize other research conducted on the semiconductor industry, review of printed materials gathered from the companies being studied including many consultant reports which had been commissioned, interviews with customers of the companies being studied to determine how good and responsive the company was in meeting market demands, and in some cases, interviews with sales representatives of the companies being studied.

In Phase III, the teams began to summarize the findings to increasingly higher levels of abstraction and generalization. First, each sub-team made conclusions regarding the findings on its company. In the next step, the business and technological sub-teams got together and created a general team summary.

In Phase IV the teams were put together into the Group Decision Support Systems facility at The University of Arizona for two brainstorming sessions called Superbowl I and Superbowl II.

Superbowl I involved an electronic brainstorming session which attempted to answer six major questions about the specialized semiconductor industry. These questions were divided into two groups, the "Business" domain and the "Information Technology" domain, according to the categorization of Parker et al (1988). The questions were: *In the Business Domain*: 1—Where is the Industry Going?; 2—How are competitors attacking each other?; 3—What are sources of competitive advantage? In the Information Technology Domain: 4—What is the role of information technology in the industry?; 5—Given this role, how well are these companies meeting the challenge?; 6—Given this challenge, what should companies do to get competitive advantage?

In Superbowl II, the group was asked to identify the key variables and sub-variables for utilization of information technology in the specialized semiconductor industry, weight these variables, then score each company as to how well it was accomplishing its mission. (The weighting and scoring of this set of data is beyond the scope of this paper.)

Company	Location	Sales 1990	Sales 1993	Strategy Type	Is/As % of Revenues	Is $/ Employee	Is $ / Chip	Type Of IT System
Analog Devices	Massachusetts	$485m	$666m	Type IV	4%	$3,487	$0.60	VAX
Burr Brown	Tucson, AZ	$177m	$169m	Type II	1.6%	$1,900	$0.11	VAX and HP
ComLinear	Ft. Collins, CO	$14m	$15	Type II	1.3%	na	na	Prime 2450 CPU with PCs
Crystal Semiconductor	Austin, TX	$5m	$100m	Type I	1.1%	$1,760	$5,641	VAX with Sun4 workstations.
Linear Technology	Santa Clara Valley, CA	$75m	$151m	Type II	<1%	$1,000	na	Minimal IS, PC-based
Maxim Integrated	Sunnyvale, CA	$56m	$111m	Type II with some Second Sourcing	1.19%	$1,761	$1,449	VAX 6000 with PCs and terminals.
Precision Monolithics	Santa Clara,CA	$88m	†	Type III	5%	$5,861	$4,069	VAX with HP 3000 system

Note: Data for Analog Devices, Burr Brown, Linear Technology, Maxim Integrated are from SEC filings. Data for Comlinear, Crystal and Precision Monolithics are estimated by Corporate Technology Direction, 1991 and 1994.
†Precision Monolithics has recently been absorbed by Analog Devices.

Table 3: Information Systems Characteristics of Seven Specialized Semiconductor Manufacturers

Results

Even though these firms were in the same sector, manufacturing precisely the same type of product, the study found they were quite different in their approach to and utilization of information technology. Producing essentially the same products[6], the supporting information systems varied from what might be termed *primitive* to *highly sophisticated and integrated.*

These differences, however, are not immediately visible if one relies solely upon strictly quantitative measures as shown in Table 3. The site visits and interviews revealed that some of the firms had virtually no information technology system all: one or two persons serving in the "MIS Department" with no relationship between job scheduling, customer service, and inventory control. Other firms had a great deal of information technology spread over the world in different manufacturing sites (typically the Far East, North America and Western Europe), but with very poor integration. These firms had a decentralized style of manufacturing and also of information technology. Many decisions regarding information technology are being made on a divisional or departmental basis, rather than from the point of view of the corporation as a whole.[7]

Other firms, some of widely different scale and business range, had highly sophisticated systems which link together all aspects of the customer service, scheduling and manufacturing processes. In addition, the highly critical element of statistical process control was also integrated into these systems.[8]

The results of the study show that the companies differed to a great degree as to how they were positioning themselves on the product life cycle curve. After much discussion, the benchmarking teams were able to identify four types of companies. See Figure 2.

The Type I Leading Edge Design House company specializes in the design of the chips, but avoids manufacturing, which is usually "sent out" to a silicon foundry for production. In this way, the Type I firm can concentrate on design and systems integration, which has a higher value-added, and at the same time pick-and-choose the foundry with the quickest turnaround time, so as to beat out the competition.

The Type II Systems Integrator and "Job Shop" Manufacturer company does the design and systems integration activities of the Type I firm, but also does its own manufacturing. Due to limited lot sizes of most products, between 1,000 and 10-100,000 items, the production tends to be highly decentralized. It is ironic that in spite of the "high tech" nature of the Type II Systems Integrator and "Job Shop" Manufacturer, its manufacturing set-up resembles a medieval guild: limited size lots, labor and skill intensity, not too much similarity from one job to the next. The Type II firm covers the product cycle from the very bottom up through the middle of the first slope. As soon as a product matures, it "hops" onto the next innovative product cycle.

The Type III Cream Skimmer firm avoids getting involved in the innovation, systems integration, or job-shop manufacturing process. Instead, it waits until a product has been proven commercially successful by someone else who is willing to take the risk, then jumps into the production cycle at the peak of the curve. Sometimes as a "second source" (a company which fills in manufacturing demand for other

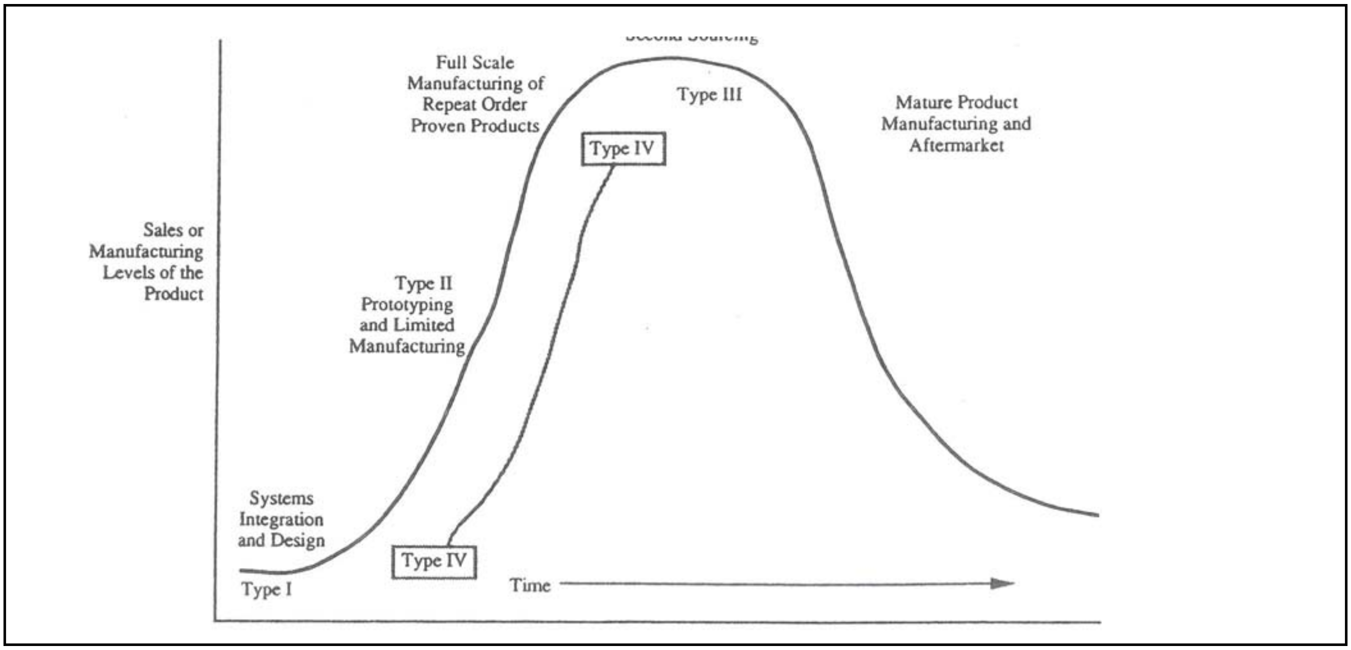

Figure 2: How the Four Types of Companies Position Themselves Against the Semiconductor Product Life Cycle

companies which temporarily can not themselves fill all the demand) or as a full scale manufacturer. In the latter case, the Type III Cream Skimmer concentrates on highly efficient manufacturing so as to gain competitive advantage from low-cost production.

The Type IV Integrated Supermarket does it all. It operates successfully over the entire range of the product cycle curve: it is active in systems integration, design, and highly efficient manufacturing on either medium-sized or large production runs. In addition, it can be a low cost producer for large orders. Only one firm we studied was a Type IV: Analog Devices in Massachusetts.

Type I, I, III, and IV firms encapsulate the basic family of strategies which are identifiable from the cases examined here. See Table 4.

Discussion

All of the firms studied are in the same sector, manufacturing similar products. We hypothesize that these firms would have roughly equivalent information systems, yet they do not. This study shows that these differences can be explained by understanding how the companies approach the Produce Life Cycle for semiconductor devices.

For firms which concentrate on the very leading edge of the production innovation curve, massive amounts of information technology are not needed because manufacturing is subcontracted away and inventory control is not complex because of limited inventory numbers in orders, and the relative short life span of the product.

As this type of firm grows greater capabilities, for example by taking on manufacturing (perhaps it develops a proprietary manufacturing process, as the companies in this group studied here in fact have); then the role of information technology increases sharply and the task is made much more complex. First of all, control of the general manufacturing process and the required statistical process control and accounting add great complexity. Second, the company has limited batch "job shop" type orders and is therefore typically manufacturing several different products simultaneously; thus raising the complexity of scheduling, resource allocation, and delivery lead time calculations. The automation required for customer service and price quotation also raises the systems cost. The problem with this situation is that as the orders increase, and as the firm grows to take on more and various types of assignments, the information technology overhead may become a great burden since it tends to be highly decentralized.

For the cream skimmer firm, the task of information technology is streamlined in the sense that it can concentrate almost solely on efficiency in manufacturing. The complexity of scheduling is decreased since the production runs are more stable. In addition, the number of products being handled is smaller, thus yielding further simplification. This type of firm, however, has limited growth possibilities because it is ultimately dependent upon "overflow" from other companies and their proprietary designs, which are never produced by the cream skimmer. The cream skimmer is always a follower, working under sub-contractor status for primary suppliers responding to high demand.

The integrated supermarket firm does everything of the job shopper except in larger numbers and with a much higher level of integration. The integrated supermarket appears to be

Growth Type	Characteristics	Type Of Products	Role Of Information Technology
Type I Leading Edge Design House	Small: 5-50 Employees. No manufacturing; use of external custom "Silicon foundries" for manufacturing. Limited Production Runs: 1,000 or less to 1x,000 units. Concentrates only on the leading edge of the Production Innovation Curve. Avoids involvement at any other part of the Product cycle.	Design of Advanced circuits. Close consultation and "co-design" with customers. Value-added through systems integration.	Heavy use of CAD. Limited or almost zero use of other information technology systems.
Type II Systems Integrator and "Job Shop" Manufacturer	Medium: 50-x,000 employees. "Job shop" manufacturing based on orders received from customers. Generally small production runs of 1,000 to 1x,000 for most customized chips. Concentrates on the initial and middle parts of the product Innovation cycle. When a product is "proven" frequently jumps off curve onto another innovative product curve, after manufacturing competition sets in.	All services of Type I, plus manufacturing. Also provides systems integration using products from other companies. Complete circuit boards in addition to single semiconductors.	Heavy use of CAD. In addition, much automation of individual departmental functions. Difficulties in providing overall integration of the firm between functions.
Type III Cream Skimmer & Second Sourcer	Small: 5-250 Employees Concentrates on manufacturing only of products which have been established in the marketplace by someone else; thus staying at the Top of the Product Innovation Curve.	Manufacturing services, including second sourcing. Does not provide design or systems integration services, except on a highly limited basis.	Concentration on systems which are used for manufacturing control, including Statistical Process Control; and Inventory Control; Customer Service Automation.
Type IV Integrated Supermarket	Large: xx,000 Employees Provides entire range of manufacturing from small orders to large. Highly Automated and World Class Manufacturing. Covers the entire range of the Product Innovation Cycle.	All Services from "Cradle to Grave" for Semiconductor Products.	Highly automated in all respects: Customer Service, Manufacturing Automation, Statistical Process Control. Has integration between different functions (not characteristic of Type III Firm)

Table 4: Type and Characteristics of Specialized Semiconductor Manufacturers

the final stage of growth and evolution for the job shopper. It can compete not only on innovation, and limited lot size manufacturing, but does not have to "jump off" the product innovation curve to seek for higher value added innovations because it is also able to manufacture efficiently. The integrated supermarket has the innovation of the design house, and the ability to produce limited run batches of the job shopper; but it also has the manufacturing efficiencies of the cream skimmer. The information systems are able to control all aspects of the firm and are a truly critical strategic asset.

Assuming that a firm might grow through the stages of the product innovation curve, then our research suggests that it is easier to grow from being a design house to being a job shopper than it is to grow from being a job shopper to being an integrated firm. In the first case, the growth is additive in nature: different production lines are added one at a time, typically with their own information systems. The job shopper becomes the sum of a large number of limited scale operations. In the second case, however, the task becomes taking a highly decentralized information technology environment and re-engineering it into an integrated system. Our research shows that this is an extremely formidable task, and two of the companies studied appeared to be "stuck" in a technological trap: having built up efficient job shop operations, they are unable to suddenly turn around to a completely different philosophy and integrate their systems.

We found one company which is a Type I, but which was building an information systems capability similar to a Type IV, although everything was in a prototype stage. Interviews revealed that the firm was consciously building into their systems from a very early stage the ability to eventually operate as efficiently as a Type IV firm. On the other hand, we found other Type I firms which seemed to be following the path of the job shopper: they were heading towards an uncontrolled, and uncoordinated, decentralized computing environment. This benchmarking study found that Crystal Semiconductor was the only firm designing its information system from the very beginning to become a Type IV company. Table 3 shows that over a 3-4 year period, after this study, while the sales of other firms grew modestly, those of Crystal grew from $5 to $100 million dollars annually.

Summary and Practical Applications

In summary, the mapping of the firm positioning against the product innovation life cycle within the context of explaining their information technology strategies has yielded these conclusions: that there is a clear relationship and that firms which appear to understand this relationship at the early stages of their development have a greater chance of growing into large integrated firms than those that fail to recognize this and adopt a different course.

There are many approaches firms can use to analyze how they should make IT investments. For many, however, the benchmarking methodology is chosen because it helps to clarify key differences with their competitors. Companies engaged in the manufacturing of specialized semiconductor devices who are benchmarking their IT investments are warned that simple comparisons without reference to their position on the PLC can be highly misleading. This suggests that further research on benchmarking needs to focus on how the external markets faced by firms can introduce variability into the study results. In particular, further research might attempt to study how approaches to the PLC in different economic sectors changes the variability of benchmarking utility.

It may be that addition of a 'PLC reference check' to benchmarking results may be applicable only in semiconductor manufacturing, but the wide variety of industries which are engaged in competing in markets which have continually reduced PLCs, such as financial services or retailing, suggests that the use of the PLC as part of benchmarking may become a standard part of the methodology.

Endnotes

[1] Measurement of chip "complexity" is difficult. For this project, we used "number of models for a single chip." This measure gives an estimation of complexity since it requires more complex chips to perform many different functions. The best measure would be number of logic elements on a chip, and number of different types of logic elements; however, it was impossible to collect this type of information for the thousands of types of chips.

[2] American companies have established a strong presence in the custom market due to superior CAD tools whereas Japanese companies have excelled at high volume products, typically DRAMs.

[3] Compaq's delay in introducing Pentium machines was a deliberate decision to avoid a premature price reduction in its 486 machines.

[4] At the time of the benchmarking study, Analog Devices had more employees.

[5] The teams were composed of graduate students at the University of Arizona, Eller School of Business, working in conjunction with a team of 5 persons from the Burr-Brown company (also located in Tucson, Arizona). Burr-Brown support the project and supplied the logistical support. Briefing the teams was done by Burr-Brown personnel throughout the benchmarking exercise. Briefings were supplemented by this author who was the overall research coordinator. The preliminary briefings and study took approximately 4 weeks, with continued study throughout the 14 weeks of the project.

[6] Although each of the companies in the sector produces the same type of product, they employ different approaches to their customers which are in a variety of markets, including defense and civilian electronics (which demand different procedures and approaches to marketing).

[7] Due to confidentiality agreements, we cannot report the direct tie between some IT factors and specific companies.

[8] Highly advanced SPC methods are critical in getting the various levels of military certifications needed for contracts involving the most sophisticated integration projects being built for the military.

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