Beating the Clock:

Corporate Responses to Rapid Change in the PC Industry

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Time management increasingly preoccupies contemporary businesses.[1] Managers seek to compress development times, production times, and delivery times; and, if possible, they try to integrate these operations into a seamless process. Often delivery times are more important than prices; failure to get the right part or component, or even the finished product, to the right place at the right time may cause bottlenecks that adversely affect an entire value chain and lead to serious losses. Companies such as Federal Express and UPS have been very successful in expanding their market space from simple delivery to an explicit emphasis on time/space management for other firms. In addition to this emphasis on shortening the duration of various activities, firms must adapt to the related problem of the increasingly rapid obsolescence of goods and of the knowledge embodied in them.[2] In the emerging industrial environment characterized by rapid new development and accelerated production and delivery times, slower-moving firms often are outflanked and experience serious difficulties.[3] Improving or creating strategies to deal with the temporal dimension of business management is of great importance to firms in the late 1990s.[4]

The personal computer (PC) industry illustrates the increased importance of time in production and distribution. From its inception, rapid rates of change have been endemic in the PC industry.[5] Dell Computer has referred to this speed of change as "velocity."[6] As an example of the current situation, product life cycles in the PC industry were approximately 1 year in the middle 1980s, but

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in 1999 they had shrunk to approximately 3 months.[7] Ever-decreasing model life cycles is only one manifestation of the increasing rate of change. According to Michael Dell, founder of Dell Computer, in 1998 the cost of materials was declining at 50 percent a year. From 1997 to early 1999 this pace of devaluation was fueled by the dramatic decline of DRAM and hard disk drive prices and the market entry of cloners of the Intel Pentium microprocessor, which forced Intel to respond with a quickening pace of price reductions. PC parts and components share attributes with perishable commodities such as fresh fruits and vegetables or high-fashion clothing.[8] In the PC industry, even more than in other computer market segments, price and time are intimately connected.[9]

In contrast to the complex tasks and decisions facing many PC component industries, the simplicity of assembly and ease with which components can be purchased have created low market-entry barriers for PC assemblers. This means purchasing, marketing, and logistics are the most important links in the value chain that the PC assemblers can manipulate to create unique advantages. One might expect that in such an environment profits would be nearly nonexistent, but that is not the case. The PC business can be highly profitable, but it is difficult to survive—as many Japanese, Korean, and U.S. firms have found to their chagrin. Missteps can be fatal: excess inventory depreciates quickly, resulting in ruinous losses, and failure to get the newest products quickly to market also leads to losses. Thus, time management has become the key to survival and success.

This article examines the dynamics of product devaluation in the PC industry and how firms have re-invented or changed their business models in an increasingly time-sensitive, competitive market. New business models are constantly being introduced. For example, the build-to-order assemblers introduced a new business model that forced the entire PC industry to rethink how it manages the value chain. The next step is likely to be the introduction of Internet-based purchasing. Simultaneously, older business models come under severe pressure.

The PC industry is a critical case study because the PC in a network is the central appliance for organizing work for an increasing proportion of the workforce.

The PC Industry Environment

The PC industry has two fundamental features. First, the modular nature of PC production and the availability of components on the open market has led to competition at nearly every stage of the value chain. Second, the high rate of product innovation, especially in semiconductors and magnetic storage, means assemblers must upgrade their products as quickly as possible or risk losses on their PCs containing older or obsolete components.

The first feature, the modular nature of the PC, is a legacy of IBM's decision to purchase the microprocessor and the software operating system from outside vendors.[10] IBM decided to outsource for several reasons, the most important of which were the desire to develop and introduce the PC quickly and the need to escape IBM's high-cost structure and ponderous bureaucracy.[11] After this decision, IBM's attempts to reestablish vertical control came to naught. So, the traditional "make or buy" decision for components was available only before introduction of the PC. After PCs were generally available, their configuration became an open standard. Of course, not all of the PCs' components are open. The assemblers' dependence on other firms in the value chain has created opportunities for "hold-up" by privileged suppliers in the value chain (the two most notable of which are Microsoft and Intel).[12] Befitting their position, they have been fabulously profitable. However, they have been careful not to exploit their position to such a great extent as to drive customers to another operating system or microprocessor design.

The modular nature of PCs means that the specifications for linking various components are freely available. Moreover, no one company in the PC value chain integrates the entire chain, and with the exception of operating system software (Microsoft) and, to a slightly lesser degree, microprocessors (Intel, AMD, Cyrix, Integrated Device Technology), there is competition at every link of the chain. In other words, the value chain is disaggregated. This does not mean that there is no value chain integration; for example, IBM assembles PCs and produces hard disk drives and some integrated circuitry. Despite this, even IBM purchases most of its components. An example of the complicated nature of the situation is the fact that IBM makes, sells, and buys hard disk drives.[13]

A PC is assembled from a combination of separately produced components with a few simple tools. The direct labor cost in final assembly is generally less than 5 percent of the total cost of a personal computer or workstation.[14] In the case of Dell, actual hardware assembly accounts for only about 10 minutes of the overall 4-hour process; burn-in and testing consumes over half the total time.[15] All the components required to assemble a PC are readily available on the open market to individuals or commercial PC assembler/marketers, but volume discounts are significant. Because of the relative ease of market entry, relative lack of scale economies or intellectual property barriers, and the simplicity of production, there is little value added in the assembly process.

The final assemblers appear to have an excellent position because they can rely upon the external capabilities of their component suppliers; i.e., the assemblers do not need to invest in research.[16] And yet, with little research and development, little protectable intellectual property, and no strong market control, the assemblers are vulnerable to pressure from key component suppliers such as Intel and Microsoft, which have a powerful ability to affect the assemblers' business position, as Intergraph Inc. discovered in its dispute with Intel.[17] Examples of this power are the reluctance of PC assemblers to testify against Microsoft in the antitrust case being litigated in Washington and Intel's threats

to withhold microprocessors from companies with which it is involved in disputes, such as patent litigation. In this environment, the assemblers find it hard to develop significant core competencies based on either research or manufacturing.[18]

The second essential feature of the PC market is its rapid rate of change. The simplest form of change is the introduction of new components. In the past, being late in incorporating the newest components led to rapid loss of market share. For example, IBM's decision to gradually switch from the 80286 Intel microprocessor to the 80386 allowed Compaq to introduce the powerful new microprocessor first in September 1986 and gain significant market share.[19] Premium pricing is nearly always concentrated in the newest components (and computers containing them), so suppliers are motivated to innovate and then do everything possible to push the new introductions into the channels as quickly as possible. Assemblers are eager to incorporate the latest technology into their systems, both because of the higher margins on cutting-edge systems, and the customers desire to run the newest PC software. This means that gaining market acceptance for new components is usually not difficult. From the introduction of the IBM PC in August 1981 there has been a gradual, but perceptible, increase in the pace of change.

With an assembled modular product, the pace of change, both technically and economically, is driven by its various components. Constant dramatic improvements in performance for roughly the same price is explained by the fact that two of the most valuable components in a PC, semiconductors and hard disk drives (HDDs), are subject to extremely rapid technological improvement. The first and most famous improvement dynamic is described by Moore's Law, which states that the performance of semiconductors will double roughly every 18 months.[20] Moreover, the new chip will be sold at roughly the same price as a chip with one-half the capability sold for 18 months earlier. Intel, the leading microprocessor producer, has made the rapid development of new product generations and sub-generations a cornerstone of its business model.[21] Similarly, in the 1990s the per-megabyte cost of HDD magnetic storage experienced an even faster decline as the density of data storage doubled every 17 months.[22] Here again, HDD makers developed a model of charging roughly the same price for their newest introductions ($300-400 wholesale) and progressively less for their older models. In performance-adjusted terms, the prices are constantly collapsing.[23]

There have been only a few studies of the price declines of the various PC components. For semiconductors used in PCs, Grimm found that from 1985 to 1996 the average annual rate of decline in the price of microprocessors per transistor was 35 percent, and for memory chips, the average annual rate of decline per transistor was 20 percent.[24] For HDDs in the PC market from 1980 to 1989, the average annual rate of price decline per megabyte of storage was 30.3 percent.[25] Thus, over 50 percent of the total PC cost is on a continuous and dramatic downward trajectory.

Given that several of the most critical components are constantly dropping in value, it should be no surprise that the performance-adjusted price of an assembled PC also drops. In a study of a number of different PC models from 1982 to 1988, Berndt and Griliches found that prices dropped between 20 and 41 percent per annum over the life of a model.[26] Based on data for the early 1990s, Steffens showed that the declines are most rapid for newly introduced PC models and are much slower for vintage models, most of which are no longer produced by the top-tier companies.[27]

The persistent tendency for the price of the most technology-intensive components to drop for any specified performance level is difficult enough to manage. However, there are also periods of extreme price instability due either to overcapacity in certain components or to increased competition in a particular component segment. For the PC assembler this means that inventory problems extend far beyond simply having capital in process and storage costs. They expose the owner not only to traditional shrinkage, but also to the risks associated with more unpredictable price declines.[28]

To gain a better understanding of the current situation, it is helpful to see how technical innovation, price erosion, and new PC firms have evolved during the 1980s and 1990s. In the 1980s, IBM was the dominant force in pricing as the premium brand and was able to extract a rent from customers in the form of 18 percent net operating margins.[29] Compaq was able to establish itself as a competitor with comparable quality, but slightly lower cost.[30] However, improving quality and the assurance of compatibility simplified market entry for second-tier producers, especially in the low-end market. They were able to offer significantly lower prices and still be profitable because Compaq had a 67 percent price premium over a comparable Gateway 2000 computer.[31]

In 1992, Compaq responded to low-cost competitors by dramatically lowering its margins and engineering costs out of its value chain. After this decision, a new pricing regime developed in which it was largely accepted that business customers would spend about $3,000 for a high-end system capable of running the most recent software and that it would be obsolete in approximately 2 years as new software applications made the computer too slow. Thus, the price for a new high-performance computer remained relatively constant at approximately $2,500 to $3,000, though performance continually improved. This was a stable environment that permitted firms anywhere in the value chain to calculate roughly what their price should be to fit into a particular price range's machines. For the computer assembler, the bulk of their profits came from these high-end machines that customers wanted so they could run the ever-larger and slower software packages.[32]

The extreme competitive pressure brought about by the relatively open market for PC parts and components places a generalized downward price pressure on PCs. Large numbers of companies occupy several component market niches such as mainboards, video and sound cards, and network cards; for example, globally there are nearly 100 companies producing mainboards.[33]

Other components, such as memory chips or hard disk drives, are produced by a smaller number of companies; but these companies are also locked in desperate competition. For example, the HDD industry, which consists of less than ten major competitors, suffers recurring large losses due to overcapacity and concomitant price pressure. In late 1997, Seagate, the market leader, took a $250 million charge for the fourth quarter of 1997 and laid off 10,000 workers because of overcapacity.[34] In 1997, even microprocessors, largely dominated by Intel, experienced more rapid than expected price declines due to the introduction of fully-compatible microprocessors cloned by Advanced Micro Devices (K6 chip) and Cyrix (6x86 MX chip). These microprocessors, roughly comparable in performance to Intel's middle market offerings, are sold at lower prices. For example, Advanced Micro Devices (AMD) promised to undercut Intel's prices by 25 percent for comparable parts.[35] In response, Intel was compelled to accelerate its pattern of regularly scheduled price reductions.[36] The only company not compelled to enter the price-cutting fray was Microsoft.

At the end of 1996, another major discontinuity in the PC market occurred as Packard Bell and then Compaq introduced sub-$1000 PCs capable of handling all popular software programs. The average cost per system sold experienced a rapid erosion as prices decreased from $1,800 for an average retail PC to nearly $1,000. In April 1999, sub-$1000 PCs accounted for 68 percent of all retail PC purchases, with sub-$600 category growing very quickly.[37] The sub-$1000 category was made possible by the development of clones of the Intel Pentium microprocessor by AMD, Cyrix, and IDT as well as the reduction of prices of memory and HDDs. The sub-$400 machine was also coming into the marketplace. This discontinuity occurred because the relationship between constantly new and larger software applications and improved hardware performance broke down. As soon as no new software demanding faster processing was introduced, the demand for high-end machines costing approximately $3,000 waned.[38]

The speed of change has not slackened, although its character has shifted to some degree. Whereas blazing speed had been the goal for microprocessors, the already existing but subsidiary goal of integrating more functions previously contained on separate chips onto the same chip with the microprocessor (the so-called "system-on-a-chip") increased in importance. For example, the Cyrix Media GX chip integrated some graphical and multimedia hardware functions into the microprocessor and main chipset. The elimination of separate chips lowered costs, further simplifying the PC and often increasing overall PC speed. In 1998, several systems producers, most notably Compaq and Hewlett-Packard, sold PCs using the Media GX for between $499 and $999.[39]

The 1997-1998 price decrease was made possible by four synchronous developments in components. First, overcapacity in DRAMs caused a bitter price war; the price per megabyte of memory dropped 62 percent during 1997 and continued to drop in 1998.[40] Second, overcapacity in HDDs triggered another brutal price war; server disk drives (9 gigabytes or more) dropped in price from

about 11 cents per megabyte in 1996 to about 5 cents per megabyte in early 1998, and they are expected to be at about 3 cents in 1999.[41] Third, and most important, three Intel-compatible microprocessor producers—AMD, Cyrix, and IDT—entered the low end of the market with much cheaper microprocessors. The final reason was that the newest "killer" application, Internet browsing, did not require a faster PC.

The standard components of a PC, such as the case, mouse, keyboard, and floppy drives showed much slower improvement and experienced far slower price declines. For example, in October 1986 a 1.2 Megabyte floppy drive cost $147 retail, but by January 1994 it had dropped to $59 and was replaced by the 1.44 Megabyte floppy that cost $39 in October 1997. This total decline was only 73.4 percent in 11 years. The power supply experienced an almost insignificant decline in price, especially when considered relative to the total cost of the system. In 1986, a 150-watt power supply cost $85; more recently the average retail price of a 250-watt power supply (sold with a case) cost from about $30 to $60, depending on the case size. For all of these components there was little technical change and limited performance improvement. Cost savings in such basic components come from decreased labor costs, economies of scale, and small design improvements.

The PC commodity chain begins with a variety of component producers, each of which specializes in a particular component, usually distributed on the open market or supplied on an Original Equipment Manufacturer (OEM) basis to assemblers. The various components provide different levels of value to the completed system. With the exception of operating system software, the higher value components tend to be more time sensitive and subject to rapid price fluctuations. These components expose system assemblers to possible losses if prices drop quickly.

A disaggregated value chain and a modular product mean that it is in the interest of every part of the value chain to encourage new competition in other segments of the value chain. So, for example, Microsoft is happy to certify microprocessors made by Intel's competitors as Microsoft-compatible, hoping that microprocessor prices will fall and consequently bring more consumers into the market. Intel, on the other hand, would be happy to have other operating systems, because that would put pressure on Microsoft's prices.[42] In a disaggregated value chain, firms at each segment do everything possible to encourage lower prices in the other segments in an effort to lower the final price and increase volume. Unlike classical vertical integration, in which financial control is exercised over inputs and distribution channels in order to extract value from the entire process, and the focus of innovation is in centralized factory nodes, the PC production system's vertical disintegration means competition in nearly all parts of the value chain. Of course, the final assemblers try to pressure component prices down to increase the profits they can retain.

The PC assemblers' competitive environment is almost uniquely difficult because of the high level of risk from decreasing inventory values and price

declines, both of which are entirely out of the assemblers' control. An assembled PC is actually a largely undifferentiated commodity product in the sense that differences in quality, design, and even manufacturing efficiency are relatively minimal.[43] There are two basic strategic approaches which the PC assemblers can utilize to deal with this situation. The first of these is to add value through the provision of ancillary services, traditionally system integration related services, but more recently bundled software and services for the consumer market. This approach is probably best exemplified by IBM, which provides a wide range of services including pre-configured internet and e-commerce server systems, business service software (including electronic data interchange-type services such as Lotus Notes), and a wide range of system installation and information system consulting. Compaq has attempted to expand its service-related offerings, as well as diversify its product offerings in the higher value server market through its acquisition of Digital Equipment Corporation (DEC) last year.[44] The concomitant strategy in the consumer space centers around PCs bundled with additional services, most importantly, Internet connection. Attempting to maintain or expand market share, particularly among first-time computer buyers, most PC assemblers are either offering, or are considering offering, Internet service as part of the purchase of a PC. The most recent strategy has been to charge full price of Internet service and essentially give away the PC. The recognition here is that the killer application is the ability to surf the Internet, not the other PC applications. In addition many PC assemblers are either creating, or entering into strategic relationships with, Internet portal sites and Internet retailers. The idea is to sell a range of services and products with higher margins than system hardware, and to garner repeat business from consumers locked into the Internet-based services bundled with the system.[45] Recently several PC assemblers have offered rebates to customers who agree to enter into three-year Internet service contracts with a selected ISP. For example, the Korean low-cost PC marketer E-machines has a deal with AOL's Compuserve. Compuserve will rebate approximately half ($400) of the cost of an E-machines PC in exchange for a long-term service contract. E-machines recently became the number three retailer of PCs in the US.[46]

The degree of product reliability, service, and support differentiates PCs, but beyond advertising and brand recognition, the main value-chain segment that the assembler can control is logistics or, in a word, time. The second strategic approach, then, is to develop high-speed logistics systems, particularly on the distribution side of the process.

Logistics: The Assembler's Response

Intense competition in both the component and finished PC markets has created a situation in which highly efficient logistics—or, more abstractly, the efficient management of time and space—have become the sine qua non of competition. The well-known and more conventionally oriented producers/-

marketers of finished PCs—such as IBM, Hewlett-Packard, Compaq, Packard Bell, and AST—have been confronted with the difficulties inherent in a business model based upon efficiently assembling PCs or using an OEM producer and then shipping PCs from the factory through a conventionally structured distribution system to the retail store. Such a model works for most traditional products, but it has significant drawbacks in the fast-changing PC industry. The PC industry is evolving from a conventional model (where assemblers rely on a just-in-time system for managing parts and component inflows in a standard three-tiered distribution system) to a model where the entire value chain, including the customer, is managed on a just-in-time basis (see Figure 1). The low value-added in system assembly, and the constant tendency for part and component prices to drop, requires assemblers to find quicker ways to assemble systems and sell them to customers.

The focus of managerial and logistical innovation has shifted from finding more efficient economies in a discrete, usually geographically delimited space (i.e., a single factory) to efficiently managing not only supply logistics, but distribution logistics as well. The move to rethink logistics has not occurred in a vacuum; it is an adaptive strategy in response to, or made possible by, telephone sales and sophisticated point-to-point shipping systems such as Federal Express, which are revolutionizing distribution systems.[47] Electronic data interchange and other sophisticated manufacturing communication and coordination technologies enable the creation of highly interconnected and interactive, and extremely complex, integrated production.

Given the large variety of readily available, interchangeable components that constitute a PC, there are many possible ways to organize the value chain. In production systems such as those for automobiles, the market for components is relatively circumscribed; an assembler utilizes some off-the-shelf parts, but many parts are designed expressly for a certain model. In contrast, PC production is a system perhaps better captured by the metaphor of a network rather than by the notion of a chain. The value chain has no single controlling entity (in the Williamsonian sense), although, as mentioned earlier, profitability is elevated for those component suppliers who occupy critical nodes in the network, e.g., the producers of key components, such as Intel and Microsoft. Since the value added in assembly is minimal, most of the value contained in a finished PC is embodied in its components. PC assemblers can add some further value by developing reliable and tested system configurations, providing technical support and service, and creating a reliable brand image.[48]

PC production is globalized insofar as the component supplier chains are geographically dispersed, although in many cases these chains are dominated by U.S. firms and technologies. The PC commodity chain consists of U.S., Japanese, Korean, and Taiwanese multinational firms that produce hard disk drives, floppy disk drives, CD-ROM drives, monitors, and memory chips. In addition, there are even more smaller firms that produce mainboards, video and sound cards, network cards, keyboards, and cases in locations such as Taiwan, Hong Kong, and

FIGURE 1. Basic PC Production System Strategies

Type	Characteristics	Main Value Leverage	Examples
Standard Mass Production	Inputs shipped to central facility; production planned on long-term basis (monthly); product marketed through standard channels	Traditional scale economies; brand identity	IBM, Compaq, Packard Bell
Global Logistics	Inputs assembled at dispersed logistics centers; production planning on a medium- to short-term basis (months or weeks); OEM producers ship directly to market channels bypassing OEM customer	Input and distribution logistics on global scale	Acer, FIC, Mitac, Tatung
VARs (Value Added Resellers)	Quasi logistics centers for standard mass producers; handle excess capacity for mass producers; handle service, integration, and configuration for large accounts; alternate retail channel	Distribution logistics, service	Micron, Microage
Small-Scale Local Producers (usually considered part of the VAR category by the industry press)	Small local shops ("screwdriver guys"); some with fairly large accounts; collectively account for approximately 25% of the market according to estimates	Know local market; best at customer service; fresh technology and easily customizable configurations; low production overhead	
Japanese Producers	Similar to standard mass producers; target high-end markets; strong brand identity	Brand name; consumer-oriented design; partial vertical integration of some components	Sony, Toshiba
Direct Marketing	Inputs assembled at central facilities; production planning on a per-order or near per-order basis; producer ships directly to retail customer	High sourcing/production/distribution throughput efficiency; component price decline differential; some scale economies	Dell, Gateway 2000

Source: Authors

FIGURE 2. Global Revenues and Ranking for PC Sales in 1997 and 1990

Ranking 1997	Company	Sales ($billions)	Ranking 1990	Company	Sales ($billions)
1	Compaq	14.35	1	IBM	9.64
2	IBM	10.8	2	Apple	3.85
3	Packard Bell NEC	9.05	3	NEC	3.62
4	Dell	8.2	4	Compaq	3.60
5	Hewlett Packard	7.6	5	Toshiba	2.49
6	Gateway	5.1	6	Olivetti	1.79
7	Apple	4.8	7	Groupe Bull	1.42
8	Acer	3.4	8	Fujitsu	1.42
9	Fujitsu	3.4	9	Unisys	1.18
			10	Commodore	1.00
			18	Hewlett-Packard	.63
			20	Dell	.55
			23	Packard Bell	.52
			33	Gateway 2000	.28

Sources: *Computer Reseller News* (June 1997); John Steffens, *Newgames: Strategic Competition in the PC Revolution* (Oxford: Pergamon, 1994), p. 335.

Singapore. The markets for PCs are globalized as well, but again, the United States is most important. The fact that the U.S. was the prime developer and earliest large-scale adopter of PC technology, along with the size of the U.S. market, has put the U.S. assemblers in a leading position. Six of the top nine PC producers with the largest gross sales are U.S.-based (see Figure 2).[49] In unit terms, in 1998, NEC/Packard Bell had dropped to fifth, as Hewlett-Packard captured the fourth spot.[50] The significant segment that is not well represented in these rankings is the Taiwanese assemblers such as Tatung, Mitac, Acer, and FIC, which (with the exception of Acer) focus mostly on the OEM market.[51] The Taiwanese producers have developed sophisticated globally situated logistics systems to serve markets not only in North America, but in most parts of the rest of the world.

The key structural element of PC parts purchasing logistics is the geographically dispersed location of parts and component suppliers. Component makers and final assemblers alike must balance lower labor costs with the costs and risks of having inventory in transit. To do this, the PC industry has had to create logistics systems that coordinate global production and are also capable of a flexible response to localized market conditions. Sourcing decisions are constantly in flux because of the velocity of change.

PC firms have recognized the importance of moving the final inclusion of the most time-sensitive components closer to the customer. This strategy is

particularly crucial for final retailers because of the risk involved in holding older PCs and parts if prices fall unexpectedly. The mail order and Internet-based retailers have adopted a system by which they do not have any computers in inventory. For example, Insight, a mail-order computer products distributor in Tempe, provides customers with a catalog (or Web page) of products. Insight handles the order and payment and simply arranges for a distributor or manufacturer to ship the product directly to the customer. In fact, eventually companies like Federal Express and UPS might even provide some aspects of final assembly as part of their services.[52] Another example of firms moving closer to the customer are the independent decisions by Ingram Micro and Fujitsu to move their PC assembly to Memphis, Tennessee, because it is Federal Express's hub. This location will enable them to receive parts more quickly and to reduce their delivery time to retailers or final customers.

In the "standard" or three-tier model that characterized the conventional assemblers, parts and components were delivered to warehouses and stored until required for assembly. The finished PCs were then shipped through conventional distribution channels (i.e., to distributors), and then to value-added resellers (VARs) or to retail stores. This standard model did not treat inventories as the most significant problem in the entire system: in effect, time was not considered as the critical business variable. In 1998, a company such as Compaq typically had about 10 weeks of inventory, which included parts, components, and finished PCs.[53] Similarly, IBM had 6 to 8 weeks of inventory in dealer channels.[54] Consequently, there were 8 or more weeks during which the PC was losing value. Of course, the value erosion experienced was not a particularly serious problem as long as other vendors had similar cycles—but it did constitute a tremendous opportunity for loss. Assuming that other business variables remain constant, the assembler and value chain retaining possession of the physical product for the shortest period will be the most efficient.

The standard three-tier model is consequently in crisis. New business models that source parts and components on a just-in-time basis and move system assembly—or at least the insertion of the most time-sensitive components farther down the distribution channel ("channel assembly") toward the final customer—are being adopted to reduce inventory holding periods. The models vary. At one end of the spectrum are companies such as Dell Computer, which has the "purest" approach in the sense that it builds systems to order and ships them directly to the customer, along with the small local shops that order parts in small quantities and produce systems customized for individual customers. At the other end of the spectrum are companies such as Compaq that mass produce (and contract mass production) in a few regional centers for sale in the channel.

The physical location of final assembly is an important factor in speed of production or delivery. Longer distances generally require greater transport time than shorter distances, although the time can be reduced by locating a firm close to an airfreight hub, such as Memphis for Federal Express. In the 1980s, with somewhat slower product cycles and long inventory holding periods, location

was relatively unimportant as long as transportation and communication linkages were adequate. Distribution channels were relatively slow, and markups were large for the market leaders such as IBM and Compaq. This provided a price umbrella under which low-cost producers from Asia could operate; for instance, Taiwanese OEM suppliers became prominent in the PC industry.[55] Generally speaking, however, during the 1980s there was no specific regionalized locational logic in the PC industry; the locations of headquarters and assembly operations were often determined by the personal background of the founder(s) or some other contingent factor unrelated to business logistics, as in the case of Dell Computer in Austin, Texas; Compaq Computer in Houston, Texas; and Gateway in North Sioux City, South Dakota.

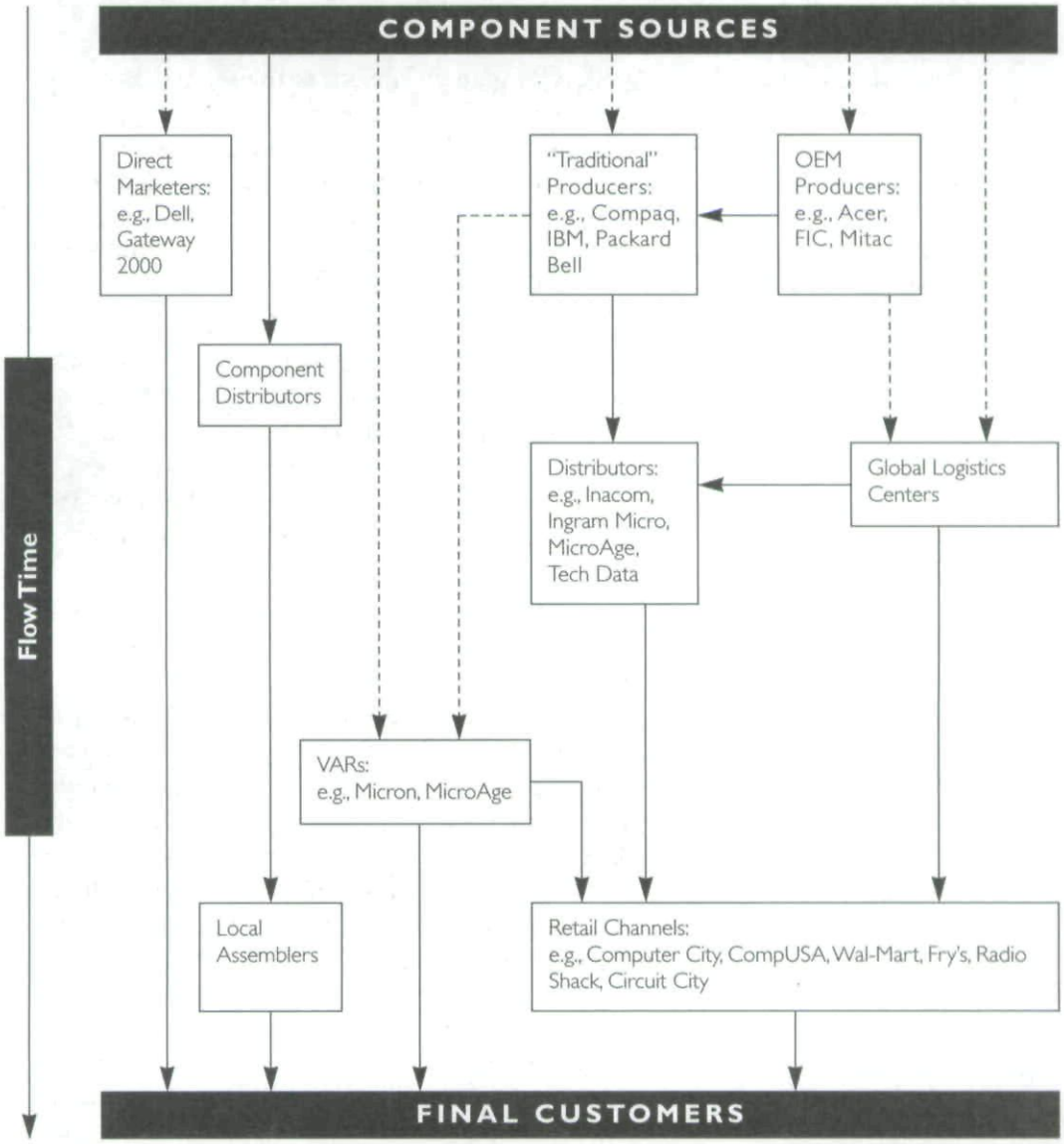
The most notable agglomeration of PC producers and PC component producers is in Taiwan. Taiwan's location in the PC value chain is largely that of an OEM supplier of relatively low value-added components and PCs, although finished PC producers such as Acer, Mitac, and FIC, along with a number of medium and small component producers, have tried, largely unsuccessfully in the U.S., to implement their own branded product strategies. The larger Taiwanese firms have established assembly and/or distribution operations near most large market regions such as Europe, North America/U.S.A., Latin America, the Middle East, and Asia. Acer has pushed this approach even further by establishing assembly/distribution sites in sub-regional locations; for example, in Latin America they have firms in Mexico, Chile, Brazil, and Argentina.

The main differences between logistic methodologies concern the size of the operation and the type of strategy. Figure 3 shows the various channels to the final consumers. Firms often utilize more than one methodology depending on the product(s) or the market(s), and there is a great deal of variation from firm to firm. Acer, for example, markets its own brand of computers through its global logistics (GL) system; assembles systems on an OEM basis; and produces some components including monitors, mainboards, sound and video cards, and memory. FIC and Mitac, while producing their own branded products, are largely in the OEM business. The large U.S. contract manufacturers, such as SCI Systems and Solectron, are also major OEM manufacturers. Producers such as Compaq, IBM, and Hewlett-Packard utilize various mixes of self-produced and OEM-produced systems marketed exclusively under their own brand and model names for the mass retail and corporate markets. Dell and Gateway are direct marketers that produce systems on a custom-order basis for the mass retail and corporate markets.

Global Logistics

Global logistics refers to a set of strategies designed to take advantage of capabilities and experience in globalized sourcing and distribution. The GL strategy is based on the recognition that system assembly is a low value-added, but time-sensitive, segment of the value chain. GL systems have been developed to manage the higher-value-added portions of the value chain involving

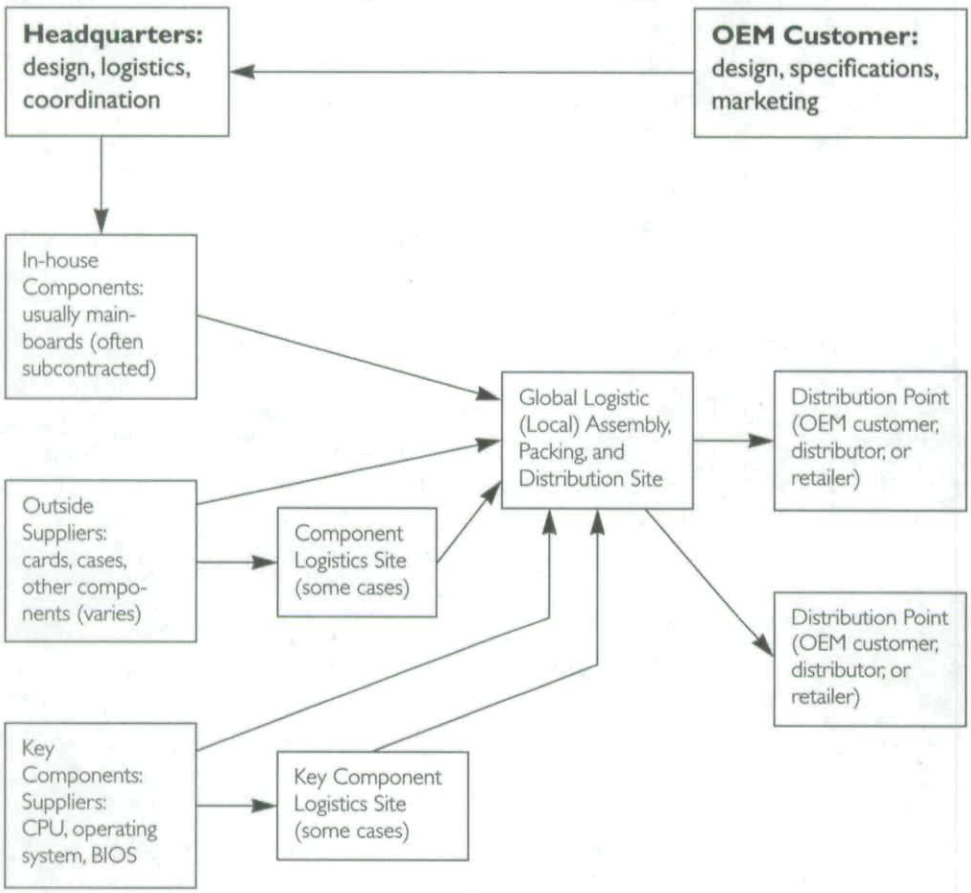
FIGURE 3. Personal Computer Logistics



Note: Broken lines indicate component flows, solid lines are finished systems.

distribution, marketing, original design manufacturing (ODM), OEM manufacturing, *and* distribution as a complete service. The majority of the practitioners of GL are based in Taiwan. Given their distance from the final markets, they had to develop a system that would protect them from component depreciation risks. Acer Computer was the pioneer of global logistics and a unique system based on

FIGURE 4. Typical Taiwanese PC Global Logistics Production Chain for OEM and Other Customers



a network of independently owned affiliates operating in foreign countries. Acer is not alone. For example, First International Computer (FIC) has its Global Operations, Local Fulfillment (GOLF) system and Mitac follows what it calls a "managistic" response to market fluctuations. Acer evocatively refers to its system as embodying the twin virtues of "global reach, local touch" and strives to operate on principles similar to the fast food industry in which "fresh technology" is brought quickly to market through local assembly and distribution outlets.[56]

The basic idea of GL is to minimize risk by establishing assembly sites or global logistics centers (GLCs) in or near the principal market area. Figure 4 shows an idealized representation of the GL system. High-value components, which are also at high risk, are purchased from the best-cost location for delivery

at a GLC. Components such as mainboards and video and sound cards are air freighted to North America from production/distribution sites in Taiwan or elsewhere in Asia. Other lower-value components, such as power supplies, cases, floppy disk drives, or components with low rates of technical change and significant bulk, such as monitors, are shipped by sea or purchased from regionally located producers.

The Taiwanese GL producers have found a (presumably) profitable market, or at least an adequate market opportunity, in providing the U.S. producers with GL OEM manufacturing as a service. This allows U.S. firms to expand sales without having to invest in expanding capacity. For example, FIC operates an assembly facility in Austin, Texas supplying Compaq.[57] The modus operandi for GL throughout the Taiwanese personal computer industry is to extract value from a number of value chain segments, though the value in any single segment may be small. So, these firms have created a system in which manufacturing (design, system development, and assembly) combined with component sourcing and distribution (logistics) is provided as a complete service to the customer. The large traditional U.S. PC marketers can use companies like Acer, FIC, Tatung, and Mitac not only as assemblers, but also as providers of design, just-in-time distribution, and marketing (i.e., logistics) services. This relieves the U.S. firms of the costs and risks of adding capacity, especially for their lower price systems with thin margins.

The global logistics system pioneered by Taiwanese firms is a response to an opportunity that arose in the mid-1980s to supply U.S. firms with inexpensive components and even finished PCs on an OEM basis. They also wanted to move "upstream" and sell their own branded PCs; however, they soon recognized the difficulties in undertaking the entire production chain in Taiwan and then exporting to foreign markets. Global logistics allow Taiwanese firms to take advantage of Asia's low-cost production and the low prices for many non-price-sensitive PC components, while permitting the insertion of the components facing rapid price erosion at the last possible moment. In large measure, the GL system overcomes the problems caused by the 2 to 3 weeks it takes to ship a finished PC by sea freight to the U.S. or another country. In this way, the GL practitioners reordered their value chain in response to the speed of change and constant price erosion. Still, GL has some limitations, one of which is that the transit time slows reaction to market shifts. Ultimately, the GL practitioners are not a severe threat to the traditional assemblers because of their lack of brand identity, somewhat slow responsiveness, and role in assembling low-end PCs for the traditional assemblers.

Channel Assembly

In an attempt to reduce inventory exposure a number of the largest PC assemblers such as IBM, Compaq, and Hewlett-Packard are shifting some final assembly operations to distributors, thereby bringing the final product closer to the customer. Their aim is to decrease inventory, increase responsiveness, and

limit price erosion. The firms handling this work are part of a broad and amorphous category called value-added resellers (VARs). VARs include distributors of relatively large parts, components, and systems and they may perform specialized system integration, system configuration (partial system assembly) services, or even whole system contract assembly for large PC marketers (see Figure 3). Major distributor VARs include CompuCom, Ingram Micro, MicroAge, and Tech Data.[58] In addition to their traditional distribution function, the VARs stock partially built PCs and configure them for their customers, which are usually other resellers.[59] The VAR category includes large and small national or regional retailers such as CompUSA (a recent entry), and numerous small local retailers that assemble partial or complete systems on their premises—usually referred to as the "build-your-own" market.[60] Channel assembly through VARs resembles the GL system, but the critical difference is that the VARs often perform a wider range of downstream functions—including, for instance, system delivery, installation, and service; network system development, installation, and service; and specialized system development. In effect, some VARs embed the PC in a package of services, thus obscuring the loss-of-value dynamics.

The VAR channel assembly model also differs from the GL and OEM approaches in that VARs take their cues from their customers, offering system "solutions" based on the lines of products they distribute. According to Tony Ibarguen, president and Chief Operations Manager of Tech Data, "the ultimate goal [of channel assembly] is delivering more value to the end user by taking significant cost out of the process, delivering a system and improving the speed and the customization and the ability to match that solution to a specific end user's requirements."[61] Channel assembly enables the larger system producers to respond to the changing PC value chain without making additional large investments in production and distribution infrastructure. By shifting some final assembly into the channel, the PC firms are able to move production closer to the customer both spatially and temporally. For example, Compaq plans to make channel assembly a significant part of its overall logistics restructuring plans.[62] Reflecting the expansion of the channel assembly approach, Ingram Micro has recently completed construction of a new plant in Memphis, Tennessee (the Federal Express global hub) and will have three other plants in the Netherlands, China, and Canada in 1999 to serve customers such as Hewlett-Packard, IBM, and Compaq.[63]

Channel assembly has two features that make it superior to the traditional model: first, it should shorten inventory holding periods; second, once the contract is concluded, the PC specifications are agreed upon and consequently the contractor need not be concerned about value erosion because it is born by the customer. There are questions, however, about the efficacy of pushing assembly down to the retail level. Channel assembly should decrease inventory in the supply chain and, if properly managed, cut overall inventory costs. The difficulty is that it might diffuse final assembly so much that economies of scale

would be lost or diminished. In effect, the channel assembly strategy decreases time from order to delivery while potentially raising production costs.

Direct Marketing

The most serious competitive challenge to the established PC companies comes from direct marketers such as Dell Computer and Gateway 2000. These companies receive customer's orders before they actually build a computer. This means they do not need to hold any inventory, thereby eliminating most inventory and concomitant risk. As Figure 3 indicates, the direct marketing model reduces to an absolute minimum the number of steps from the factory to delivery of the finished PC to the customer.

The direct marketers operate a true pull system for pre-assembly inventory and distribution, rather than a pre-assembly pull system and a distribution push system. In the case of Dell, orders are received via phone, fax, or Dell's Internet Web site. Once an order is completed and payment arrangements are confirmed, a production invoice is electronically forwarded to the production facility and the requisite parts are ordered from the vendors. Parts and components are delivered as needed per customer order from vendor warehouses located within 20 minutes of the Dell factory.[64] Dell subcontracts mainboards from three regional suppliers located 15 hours away in Mexico.[65] The finished PCs are then packed and shipped directly to the final consumer, or to a system integration contractor, nearly immediately after the assembly process is completed. According to Michael Dell, they have "eleven days inventory (including) goods in transit in both directions, spare parts, the whole thing."[66] Put differently, in 1998 Dell operated on an 11-day inventory cycle and was able to turn over its inventory thirty-three times per year.[67]

The arrangements Dell has made with its monitor supplier, Sony, are ingenious. Sony never sends the monitor to Dell; rather, when the Dell computer is completed, UPS or Airborne Express picks up the monitor from Sony's Mexican factory, matches the monitor and the proper computer at its delivery center, and delivers them as a package to the customer.[68] With this system Dell eliminates monitor inventory and saves approximately $30 on shipping costs.[69]

Dell is organized to leverage the rapidly declining value of various PC components. Dell has recognized that the decline in value can provide an important competitive advantage to a company able to compress their supply chain and manage logistics time. Michael Dell summed it up this way:

> Seven days doesn't sound like much inventory, but 168 hours does. In a business where inventory depreciates by 1 percent per week, inventory is risk. A few years ago no one in this business realized what an incredible opportunity managing inventory was.[70]

What Michael Dell discovered is that managing inventory was a key to success in the PC business.[71]

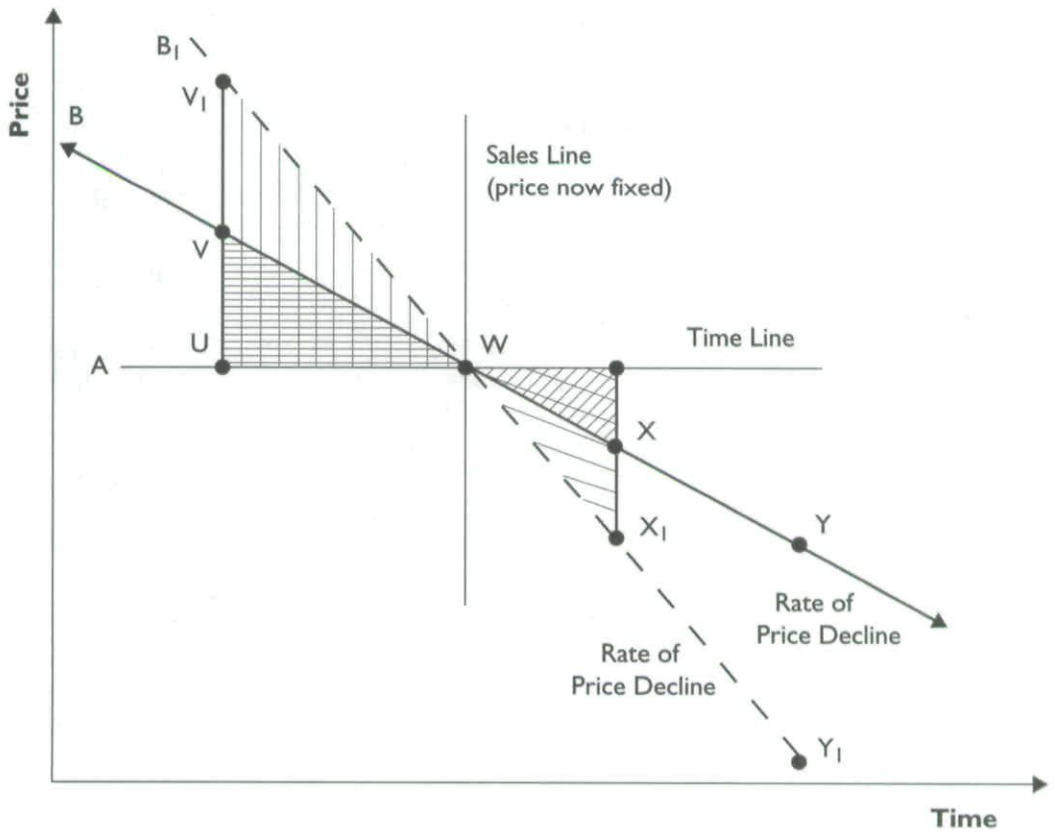
Direct marketers have two significant advantages over their competitors. First, they need not be overly preoccupied with value erosion caused by throughput discontinuities. Inventories reflect only immediate real need. Since distribution is direct, minute changes in demand are registered immediately and losses attributable to faulty demand forecasts are virtually nonexistent. Even better, because input inventory is essentially managed by Dell's suppliers, Dell is nearly free of exposure to declining prices. Second, machines are built upon receipt of payment so there are no losses from inventory waiting to be sold. In other words, the direct marketing model permits Dell to manage both upstream and downstream inventory.

Direct Marketing and Time

Business models must take into account the effects of the continuous secular decline in component prices. PC assemblers must keep inventory to a minimum and possess components for as little time as possible. Figure 5 illustrates the direct marketer's advantage over the traditional producer's business model. Line B and B_1 represent the aggregate component cost curve trending downward. B is a more gradual slope of 30 percent per annum, B_1 is approximately 50 percent per annum. The model assumes that the traditional firms' and the direct marketers' PCs are sold at the same point in time (Point W). For the traditional firm and its retailers, W is also the delivery time. Point U on Line A is when the traditional firm purchases the components. The loss of value they experience depends on the slope of Line B. In the more gradual case, it is the area represented by UVW. In the more rapid decline it would be the area bounded by UV_1W. This graphically illustrates how a more rapid decline in component prices favors the direct marketers.

There is, however, an even more interesting phenomenon. When the direct marketer sells a computer at Point W, it does not need to deliver the computer at the time of purchase. Notice the immediate benefits mentioned earlier. It has no risk of unsold inventory in the channel or on its shelves. It orders what it has sold. Another advantage is that the customer bears the costs of any price decreases that occur.[72] So, at the margin, if direct marketers shipped the computer the day the order was received, neither the direct marketers nor the customer would experience any price erosion. However, if the direct marketers did not order the parts for 5 days and then received the parts in 2 days from the component vendors (and paid that day's price on delivery) its actual cost would be Point X or X_1 on Lines B or B_1. In effect, the direct marketer would gain the area represented by either WXS or WX_1S. Finally, the customer receives their PC on Y or Y_1. Their consumer loss of value would be WYT or WY_1T. This is a benefit that the traditional manufacturer cannot capture. Of course, should prices increase, an unusual and only temporary event, the direct marketer would lose. If prices were dropping 1 percent per week on a $3,000 computer, this is $30 in profit. A similar advantage shows up in the cash flow situation.

FIGURE 5. Hypothetical Comparison between the Traditional Assembler and the Direct Marketing Logistics Model



Source: Martin Kenney ©1998

According to a recent article in *Fortune*, "Dell has a cash-conversion cycle—the difference between the time it pays its creditors and the time it takes to get paid —of negative 8 days."[73] The most interesting point about the direct marketing model is the faster the price declines, i.e., the slope of Line B, the better the situation becomes and the worse it is for the non-direct marketers.

The direct marketing approach is a significant advance in that it not only deals very efficiently with the problem of declining component prices by turning it to its advantage; in addition, it has some control over its profits by just stretching out the time required to deliver customers' orders. The direct marketing model reverses the usual process whereby revenues are collected after the product is manufactured. For most customers a wait of 2 or 3 weeks for delivery is not a problem; in fact, many customers probably expect even longer waits. Since Dell is essentially able to produce a PC in one day, it can, in effect, use the time

factor by making delivery (i.e., building the machine) with a time lag acceptable to the customer.

To test this theory about the delivery system, we gathered data about University of California, Davis, computer purchases from a major direct marketer. We found that for 159 purchases of desktop, notebook, and server PCs from July 30, 1997 to January 30, 1998, the average elapsed time from when the purchase order was faxed to the direct marketer to the delivery date was 19.01 days. The shortest wait was 7 days and the longest was 37 days. If we generously assume an average of 5 days delivery time, then an average of 14 days remains to complete the PC. If it is assumed, very generously, that parts ordering and manufacturing actually consume 5 days, then there is 9 or more days during which prices can decline from the purchase cost.

The direct marketers' approach, as well as the development of the global logistics model, are the key drivers of structural change in PC production and distribution. The direct marketing method represents a "virtual" response to the component price decline problem. Of course, there are limitations to the direct marketing model, since many customers are uneasy about ordering computers by phone or Internet, or they are concerned about the quality and availability of service and thus still prefer to deal with a local retailer or a VAR. Despite these obstacles, the direct marketers continue to capture market share.

The success of the direct marketing model, both in terms of managing component price declines and production efficiency, is forcing conventional assemblers (e.g., IBM, Compaq, Packard Bell) to make significant changes in their own logistics.[74] Compaq, currently the PC assembler with the largest overall market share, has begun to implement a number of important adjustments to its production logistics system.[75] Under its Optimized Distribution Model, Compaq will ship partially configured computers to VARs where final configuration will take place.[76] In addition, Compaq plans to start producing computers for the business market (large accounts) on a made-to-order basis.[77] In 1999, Compaq began a major effort to sell PCs over the Internet. IBM has implemented its Advanced Fulfillment Initiative and reduced dealer inventories by about 4 weeks.[78] Packard Bell has similar plans to move from a forecast-based production model to one in which machines are built to order for business customers.[79] Packard Bell's approach will be to stock a supply of parts and components so that orders can be filled within 5 days of being placed. Given the large inventory that the traditional producers currently hold, decreased inventory will increase their competitiveness. Yet, the direct marketers continue to have the advantage of removing risk through their build-after-sale model and the ability to benefit from component price declines that occur after a sale is made.

The response by the assemblers such as Compaq and IBM to the direct marketing threat has alarmed some distributors and retailers who fear that these companies are aiming to bypass them completely. The traditional manufacturers face a difficult situation because their logistics system suffers from an inherent inefficiency. The recent introduction of sub-$1000 machines does not address

the direct marketing challenge because the system still lacks the temporal advantages of the direct marketers. The more powerful response appears to be the integration of the PC into a package of services. In other words, the PC becomes a physical component of a total information technology solution. This is IBM's advantage when it provides a firm with a bundle of services and equipment. When Compaq purchased DEC in late 1998, it acquired DEC's service and sales organization, whose competency was in providing total solutions for business customers.[80] Although not driven by the typical "market versus hierarchy" concerns identified by Williamson[81] and Coase[82] (such as "hold-up"), integration provides value to the customer and submerges the devaluation dynamic in the total solution.[83] However, this development is unlikely to be sufficient to stymie the growth of the direct marketers.

Conclusion

Time management has always been a challenge for manufacturers and distributors. Marketers of perishable food and clothing also face the problem of getting their products to market before their value erodes.[84] Conventional manufacturers strive to match inventories with demand in the most efficient way possible. What distinguishes the PC industry is how time management has become a crucial competitive weapon. The evolution of Dell's system poses a stunning challenge to the PC industry: Virtually all the recent structural change in PC production is a response to Dell and Gateway—and to the small VARs, whose low overhead and proximity to the customer has enabled them to garner about 30 percent of the market collectively. Conventional PC assemblers are thus faced with two strategic responses: develop more efficient ordering distribution logistics and/or expand their service capabilities so that the PC price is submerged in a larger contract.

The primary importance of distribution logistics in the PC industry raises two important questions. The first concerns the applicability of the direct market model to the PC industry as a whole. Will the direct marketing approach eventually become the industry-wide norm? It is likely that Dell and Gateway will continue to be quite successful, but their model may be limited to the high- and medium-cost market segments. Dell's avoidance of the low-end boxes reflects not only its drive for higher-margin segments, but its reliance on a largely institutional consumer base. Currently, Dell's market base prefers more powerfully configured systems, but its price per PC will erode.

Traditionally, Dell has eschewed building its own service infrastructure. It relies on independent local PC service firms, the sophistication of its customer base, and the system integrator VARs that install Dell products. This allows a nearly fanatical focus on production and distribution logistics having a profoundly positive impact on Dell's balance sheet. It also avoids the high overhead costs of more service-oriented firms such as Compaq/Digital and IBM, but ignores the sizable part of the market that desires integrated solutions. But, here

again, Dell is searching for ways to become involved in service-intensive sales and marketing without abandoning its current advantages. Other companies, such as Compaq, are seeking to augment their service and integration capabilities while simultaneously attempting to mimic Dell by utilizing some variant of channel assembly and developing their own direct sales systems. This bifurcated strategy is risky in that system integration services require expensive overhead, and direct sales efforts threaten to alienate existing distribution channels. Given current PC market structure, one of Dell's main strengths is its ability to maintain the purity of its direct marketing model.

Dell's influence then, is based primarily on how it deals with the problem of loss of value as a function of time. Thus we come to the second important question which relates to the influence of the PC industry's logistics management on other industries. Does the PC industry represent the cutting edge of a manufacturing and distribution system that will eventually spread to the economy as a whole? Even if other businesses are not directly influenced by changes in the PC industry, the generic issues—information exchange, rapid product development, manufacturing throughput, and rapid distribution of products to market—cut across many industries. The unique qualities of the PC—such as its modular construction and deverticalized industry structure, strong universally accepted interface standards, high level of configurability, rapid component innovation, and its fragmented market—make it unlikely that the kind of channel assembly and direct marketing approaches utilized in PCs could be transferred wholesale to all other products. And yet, as integrated circuitry becomes an ever-greater proportion of the value of other products, production of such goods might also begin to be driven by PC-like price trajectories. If these tendencies continue, then new business models based on managing price erosion may become more prevalent.

Abernathy et al. provide a detailed, exhaustive discussion of the increasing efforts to control logistics and time in the garment industry.[85] Baldwin and Clark argue that automobiles are becoming more modular and some hyperbolically suggest that automobiles are becoming "chips" on wheels.[86] More generally, many industries such as machine tools, telecommunications equipment, and publishing are experiencing accelerated rates of change leading to increasingly powerful loss-of-value dynamics. In August 1999, Toyota announced that its Canadian factory would be the first of its plants to move to a five-day turnaround on customer-ordered autos. If customer ordering can be implemented nationally, then the 30-to-60 days of inventory in the pipeline could be eliminated at an enormous savings in inventory, depreciation, and other costs. This is the establishment of the preconditions for applying the direct marketing model to autos.

Ultimately, the application of the Internet to PCs and every other industry means that the direct marketing model pioneered in PCs will be adopted by ever more industries. In this sense, the PC industry is a "model system" for managers in almost every other industry. Innovative managers should be able to find

much to inspire them from this case study of the management of PC production logistics. Opportunities may be found to adapt the advantages of channel assembly, direct marketing, and even modularity to new or existing product lines. It is likely that in the next decade students of business organization will trace, at least partially, the origins of new value-chain management methods to the current era of PC value-chain management.

Notes

1. Preoccupation with time management is not entirely new, Chandler showed how a multidivisional firm was organized to cope with new technologies, and implicit in organization was managing time. Alfred Chandler, *Scale and Scope: the Dynamics of Industrial Capitalism* (Cambridge, MA: Harvard University Press, 1990). Landes discusses the role of clocks in the making of the modern capitalist world. David Landes, *Revolution in Time: Clocks and the Making of the Modern World* (Cambridge, MA: Harvard University/Belknap Press, 1983). O'Malley points out the importance of railroads and telegraphs in the standardizing U.S. timekeeping. Michael O'Malley, *Keeping Watch* (New York, NY: Viking, 1990). The acceleration of commerce contributed to an increasing need to keep accurate time. Slightly later, Frederick Taylor began the formal study of time in production, in an effort to increase worker output. Just-in-time production explicitly recognizes the need to manage time.
2. Martin Kenney and James Curry, "Knowledge Creation and Temporality in the Information Economy," in Raghu Garud and Joe Porac, eds., *Cognition, Knowledge, and Organizations* (Greenwich, CT: JAI Press, forthcoming).
3. Richard D'Aveni, *Hypercompetition* (New York, NY: Free Press, 1994).
4. George Stalk and Thomas M. Hout, *Competing Against Time: How Time-Based Competition Is Reshaping Global Markets* (New York, NY: Free Press, 1990); Joseph D. Blackburn and Joseph C. Blackburn, *Time-Based Competition: The Next Battleground in American Manufacturing* (New York, NY: Irwin Professional Publishers, 1990); Charles Fine, *Clockspeed: Winning Industry Control in the Age of Temporary Advantage* (Reading, MA: Perseus Books, 1998).
5. L. J. Bourgeois and Kathleen M. Eisenhardt, "Strategic Decision Process in High Velocity Environments: Four Cases in the Microcomputer Industry," *Management Science*, 34/7 (1988): 816-835.
6. Gary McWilliams, "Michael Dell: Whirlwind on the Web," *Business Week*, April 7, 1997. This paper focuses on IBM standard PCs. Apple Computer is not discussed because it has only a 6-percent market share and is therefore nearly irrelevant to the microcomputer industry as a whole.
7. It is important to be careful when interpreting product life cycles in the PC industry. Though the life of the model may be only 3 months, actually the top-of-the-line model often simply becomes a mid-range product, rather than an obsolete product, when the new model is introduced.
8. Stan Shih, *Me-Too Is Not My Style: Challenge Difficulties, Break Through Bottlenecks, Create Values* (Taipei: Acer Foundation, 1996).
9. The velocity of change in the PC industry results from the extremely rapid pace of technological innovation in components. Surprisingly, the PC assemblers, though absolutely dependent upon technical change, have extremely low research and development (R&D) expenditures. The suppliers perform the R&D and develop new technology. For example, in fiscal year 1997 Dell spent 1.62 percent of sales on R&D and Compaq spent 2.25 percent.

10. Richard Langlois and Paul Robertson, "Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries," *Research Policy*, 21 (1992): 297-313.
11. James Chposky and Ted Leonsis, *Blue Magic: The People, Power and Politics Behind the IBM Personal Computer* (New York, NY: Facts on File Publications, 1988).
12. Bresnahan and Richards term this "vertical competition." Timothy Bresnahan and John Richards, "Local Competition in Information Technology," paper for the 11th Annual NBER-TCER-CEPR Conference "Competition Policy, Deregulation, and Re-regulation," December 18-19, 1998, International House of Japan, Tokyo, Japan.
13. David McKendrick, "Sustaining Competitive Advantage in Global Industries: Technological Change and Foreign Assembly in the Hard Disk Drive Industry," Report 97-06, The Data Storage Industry Globalization Project, IR&PS, University of California, San Diego, 1997.
14. Jacqueline Warnke, "Computer Manufacturing: Change and Competition," *Monthly Labor Review* (August 1996), pp. 18-29.
15. Joseph Maglitta, Special DELL-ivery," *Electronic Business* (December 1997), pp. 43-47.
16. Richard N. Langlois, "Creating External Capabilities: Innovation and Vertical Disintegration in the Microcomputer Industry," *Business and Economic History*, 19 (1990): 93-102.
17. Intergraph, Inc., 1998, http://www.intergraph.com/intel/order.htm
18. For a discussion of this problem from a slightly different perspective, see Michael Borrus and John Zysman, "Globalization with Borders: The Rise of Wintelism as the Future of Global Competition," *Industry and Innovation*, 4/2 (1997): 141-167.
19. Paul Carroll, *Big Blues: The Unmaking of IBM* (New York, NY: Crown Trade Paperbacks, 1993).
20. Gordon Moore is one of the founders of Intel, the world's largest semiconductor company and most important producer of microprocessors for the PC.
21. Don Clark, "A Big Bet Made Intel What It Is Today: Now It Wagers Again," *Wall Street Journal*, June 6, 1995. Intel's strategy was to sell its newest and fastest microprocessor at very high prices. As faster models are introduced, the prices for earlier models are significantly reduced.
22. McKendrick, op. cit.
23. Gabrielle Jonas, "Outlook Bleak for Disk Drive Makers," *TechWeb TechInvestor*, http://www.techweb.com/investor, January 7, 1998. There are several reasons for these falling prices, but one of the most important stems from the rapid technological progress in the semiconductor and HDD industries. For semiconductors, see Nile Hatch, "Learning Effects in Semiconductor Fabrication," Competitive Semiconductor Manufacturing Program, Engineering Systems Research Center, UC Berkeley, ESRC 96-26, 1996.; for HDDs, see Christian Terwiesch, Roger E. Bohn, and Scott M. Hampton, "The Economics of Yield-Driven Processes," Information Storage Industry Center, UCSD, Working Paper No. 97-04, 1997.
24. Bruce Grimm, "Price Indexes for Selected Semiconductors," *Survey of Current Business*, 78/2 (February 1998): 8-24.
25. Clayton Christensen, "The Innovator's Challenge: Understanding the Influence of Market Environment on Processes of Technology Development in the Rigid Disk," DBA dissertation, Harvard Business School, 1992.
26. Ernst Berndt and Zvi Griliches, "Price Indexes for Microcomputers: An Exploratory Study," in Murray Foss, Marilyn Manser, and Allan Young, eds., *Price Measurements and Their Uses* (Chicago, IL: University of Chicago Press, 1993), pp. 62-93.

27. John Steffens, *Newgames: Strategic Competition in the PC Revolution* (Oxford: Pergamon, 1994), pp. 254.
28. Examples of crisis vary. For example, the 1997 collapse of the Korean currency and economy prompted Korean firms to flood the world economy with DRAM chips at devastating prices. Any PC maker with DRAMs in their pipeline immediately lost value. Similarly, any event that slows consumer purchasing affects PC makers with PCs in the pipeline because the inventory continues its inexorable decline in value.
29. *Business Week*, "Compaq: How It Made Its Impressive Move Out of the Doldrums," November 2, 1992, pp. 146-151.
30. It also offered the first IBM-compatible luggable computer. Rick Whiting, "Personal Computer Have-Nots Fight for Bigger Slice of Market," *Electronic Business*, October 30, 1989, pp. 34-35.
31. *Business Week*, "Compaq: How It Made Its Impressive Move Out of the Doldrums," November 2, 1992, pp. 146-151.
32. In this sense, the much decried "bloatware" was great for the PC industry.
33. James Curry, "Vertical Control in Horizontally Organized Industries: The Case of PC Mainboard Production," El Colegio de la Frontera Norte, Departamento de Estudios Sociales Cuaderno de Trabajo, Working Paper, 1998.
34. C-Net, "Seagate Sees Major Q2 Loss," C-Net News.Com, http://www.news.com/News/Item/0,4,17915,00.html, January 8, 1998.
35. Kelly Spang, "AMD Reveals a Proactive Approach to Intel Competition," Computer Reseller News, http://www.crn.com, April 20, 1998.
36. WSJ—Wall Street Journal Interactive Edition, "Intel Will Cut Prices of Chips as Rivals Eye Piece of Market," Wall Street Journal Interactive Edition, http://interactive.wsj.com, June 12, 1997.
37. StoreBoard, "Retail Desktop Market Share by Price Class, March vs. April," July 14, 1999.
38. The exception here is the server market, where the dramatic increase in Internet traffic is fueling demand for more Wintel-based server PCs.
39. Dean Takahashi and Evan Ramstad, "Cyrix's Low-Cost Chip Is Key to New Compaq PC," Wall Street Journal Interactive Edition, http://interactive.wsj.com/, February 20, 1997; Tom R. Halfbill, "Disposable PCs," *Byte* (February 1998), pp. 62-74;WSJ—Wall Street Journal Interactive Edition, "Cyrix's Low-Cost Chip Is Key to New Compaq PC," Wall Street Journal Interactive Edition http://interactive.wsj.com, February 20, 1997.
40. Kelly Spang, "Plunging Parts Pricing Keeps Sub-$1,000 PC Afloat," Computer Reseller News, http://www.crn.com, January 21, 1998.
41. David Gabel, "Server Disk Drives in the Spotlight—Hands-On Tests of High-Capacity, Fast Drives Aimed at Server Usage in Low to Midrange Niches," VAR Business, http://pubs.cmpnet.com/vb/MAIN/, April 13, 1998.
42. Sadly for Intel and every other company in the PC value chain, Microsoft's operating system software appears to be particularly invulnerable to cloning.
43. The question of product differentiation is quite interesting in the PC industry. Within the IBM standard, which is the subject of this article, there is essentially one standard architecture: Intel CPU-based systems running Microsoft operating system software. Insofar as the "Wintel" architecture is an open system that holds a dominant position in the market, the various component and application software producers must market products that conform to the standard. The primary points of differentiation concern CPU speed, the amount of memory, the software bundle, and the perceived quality and reputation of the marketer. In the past few years, some producers have attempted to differentiate their products through the design of the box, in most cases with a sophisticated design, in a color other than

basic beige, or by adding special features or integrated speakers to the monitor. Incorporating high-quality sound and video is one possible avenue PC assemblers could take to differentiate their products, but one that is limited by market demand for low-price systems. One PC producer that has tried this approach, Sony, has met with only limited success. Another approach is to configure systems for broadly defined market segments, e.g., home systems (game-playing systems), small office systems, or corporate-market systems. PCs, though easily customizable, are essentially commodity products, which means that the successful assemblers are those which can mass produce a wide range of custom configurations and get them to market quickly.

44. Even Ramstad and Jon Auerbach., "Compaq to Acquire Digital, Once an Unthinkable Deal: The PC Maker Grew Rapidly As Competitors Shunned Risk," Wall Street Journal Interactive Edition, January 27, 1998.
45. This is a variation on Microsoft's strategy of providing Internet service subscription links, either to Microsoft's own internet service (MSN) or to Internet service provider partners, on the windows desktop screen.
46. C-Net, "Free PC Offers Boost June Sales by 35 Percent," C-Net News.Com, http://www.news.com/News/Item/0,4,39642,00.html, 1999.
47. Todd Lappin, "The Airline of the Internet," *Wired*, 4/12 (December 1996).
48. The open market for components, increasingly marketed with their own branding strategies is also somewhat problematic for the brand-name PC assemblers. Sony, a company with one of the strongest brand identities in consumer electronics, has met with considerable difficulty in transferring their brand identity into the PC market.
49. One of these eight, Packard Bell-NEC, based near Sacramento California, is a subsidiary of NEC, a Japanese firm.
50. IDC, "Big Fourth Quarter Tops Off Healthy 1998 in U.S. and Worldwide PC Markets, According to IDC," http://www.idc.com/Press'Current/012999Apr.htm, 1999.
51. Acer has a large presence in the OEM market, recently completing a $2 billion deal with IBM to supply computers. WSJ—Wall Street Journal Interactive Edition, "Acer Signs $2 Billion Pact To Supply IBM With PCs," Wall Street Journal Interactive Edition, http://interactive.wsj.com, December 11, 1996. In addition, Acer is the most aggressive Taiwanese brand-name producer, reflecting the conviction of its founder and CEO Stan Shih that Taiwan's computer industry must go beyond the limitations of OEM work into the potentially more profitable marketing end of the value chain (see Shih, op. cit.).
52. See Lappin, op. cit.
53. Susan Pulliam and Evan Ramstad, "Heard on the Street: Compaq Deal May Mask Problems in PC Business," *Wall Street Journal*, February 12, 1998.
54. Carol Haber, "PC Pricing a Killer in IBM 1Q," *Electronic News*, April 27, 1998, pp. 47-48.
55. David Angel and James Engstrom, "Manufacturing Systems and Technological Change: The U.S. Personal Computer Industry," *Economic Geography*, 71/1 (1995): 79-102.
56. Shih, op. cit.
57. Takahashi and Ramstad, op. cit.
58. CRN—Computer Reseller News, "COMDEX Fall 1997 Panel Talks: What is the ultimate goal of channel assembly programs? Is it more than just to take market share away from Dell and Gateway?" Computer Reseller News, http://www.crn.com, December 8, 1997.

59. Jim Carlton, "Ingram Micro Posts 40% Rise in Net; PC Distributor Solidifies Top Position," Wall Street Journal Interactive Edition http://www.wsj.com/, April 29, 1998.
60. Jesse Berst, "Why Your Computer Retailer Will Die, and Then Come Back to Life Again," ZDNet AnchorDesk, http://www.zdnet.com/anchordesk/story/story_1240.html, September 10, 1997; George V. Hulme, "Beyond Better Prices—Quality at the Root of Homegrown PCs," Computer Reseller News, http://www.crn.com, November 17, 1997; John Longwell, "Debating the Meaning of Assembly—When Terms Break Down," Computer Reseller, *News* http://www.crn.com, August 25, 1997.
61. CRN, op. cit.
62. Evan Ramstad, "Switch at Compaq May Lower PC Prices, Heat Up Competition," *Wall Street Journal*, March 31, 1997; James Gruener, "Compaq Introduces New Manufacturing Strategy," *PC Week*, July 10,1997.
63. Michael Kanellos, "Ingram to Make PCs for Big 3," C-NET News.Com, http://www.news.com/, March 10, 1998.
64. Maglitta, op. cit.
65. McWilliams, op. cit.
66. Michael Dell, "Interview: Michael Dell," *Upside* (April 1998), pp. 98-102, 140-146.
67. WSJ—Wall Street Journal Interactive Edition, "Dell Profit More Than Doubles, Topping Analysts' Expectations," Wall Street Journal Interactive Edition, http://interactive.wsj.com, August 20, 1997.
68. Joan Magretta, "The Power of Virtual Integration: An Interview with Dell Computer's Michael Dell," *Harvard Business Review*, 76/2 (March/April 1998): 72-84.
69. McWilliams, op. cit.
70. Andy Serwer, "Michael Dell Rocks," *Fortune*, May 11, 1998, pp. 59-70, 62.
71. It is not clear that Michael Dell always understood this. In the late 1980s, Dell made an abortive attempt to enter the retail market. It is only after this debacle that Dell optimized its model of direct sales. Mark Henricks, "Michael Dell," *Spirit* (May 1998), pp. 26-31.
72. During the last 16 years, prices have only increased in a few components during relatively short periods of time. Of course, if prices increase and there are shortages, Dell would have problems, but these should be no more difficult than for any other firm.
73. Serwer, op. cit.
74. WSJ—Wall Street Journal Interactive Edition, "Price Cuts Unveiled by Compaq: Will Likely Start New Skirmish," Wall Street Journal Interactive Edition http://interactive.wsj.com, July 10, 1997.
75. Gruener, op. cit.
76. Cade Metz, "Order Up! Compaq's New Strategy Cuts PC Prices Across the Board," *PC Magazine* (1997).
77. (Gruener 1997; Ramstad 1997)
78. Haber, op. cit.
79. Jim Carlton, "Packard Bell Plans Direct Sales of PCs to Business Customers," *Wall Street Journal*, June 18, 1997.
80. Fine, op. cit.
81. Oliver Williamson, *Markets and Hierarchies: Analysis and Antitrust Implications* (New York, NY: Free Press, 1975).
82. Ronald Coase, "The Nature of the Firm," *Economica*, 4 (1937): 386-405.
83. Masten et al. found that temporal issues can "be given a major determinant of organization form," which in their case referred to the "integrate" or "buy" decision. Integration in our case is driven by the customers' desire for a seamless

solution. Scott Masten, James Meehan, and Edward Snyder, "The Costs of Organization," *The Journal of Law, Economics, and Organization*, 7/1 (1991): 1-25, 20.

84. Frederick Abernathy, John Dunlop, Janice Hammond, and David Weil, *A Stitch in Time: Lean Retailing and the Transformation of Manufacturing* (New York, NY: Oxford University Press, 1999).
85. Ibid.
86. Carliss Baldwin and Kim Clark, "Managing in an Age of Modularity," *Harvard Business Review*, 75/5 (September/October1997): 84-93.