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CLOCKSPEED-BASED STRATEGIES FOR SUPPLY CHAIN DESIGN*[1]

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This paper discusses a framework for strategic supply chain design that rests on an assortment of conceptual approaches. These approaches include benchmarking fast-evolving industries to posit principles of supply chain dynamics and integrating supply chain design into the concurrent processes of product and manufacturing system design. These approaches yield insights into sourcing strategy as well as implementation of concurrent engineering.
(CLOCKSPEED; SUPPLY CHAIN; OUTSOURCING; CONCURRENT ENGINEERING)

Biologists study fruit flies because their fast rates of evolution permit rapid learning that can then be applied to understanding the genetics of slower-clockspeed species—like humans. During the past decade, I have been studying the supply chains of the *industrial* equivalent of fruit flies—fast-clockspeed industries, such as Internet services, personal computers, and multimedia entertainment—in search of robust principles for supply chain design. The most important lesson from the industrial fruit flies is one that should prove heartening to the supply chain community. I phrase it as follows: The ultimate core competency of an organization is "supply chain design," which I define as choosing what capabilities along the value chain to invest in and develop internally and which to allocate for development by suppliers. In a fast-clockspeed world, that means designing and redesigning the firm's chain of capabilities for a series of competitive advantages (often quite temporary) in a rapidly evolving world.

Beware of *Intel Inside*

Consider the evolution of one of the information-rich fruit flies of the late twentieth century—the computer industry. In the early 1980s, when IBM launched its first personal computer (PC), the company pretty much was the entire computer industry. IBM was a technologically deep organization that designed and produced its super-sophisticated mainframe products almost exclusively with internal capabilities. But the PC presented IBM with a special "three-dimensional concurrent engineering" challenge: The company needed to create

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[1] Parts of this paper are based on chapters in Charles H. Fine, *Clockspeed*: *Winning Industry Control in the Age of Temporary Advantage,* Perseus Books, 1998, 1999.

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a new product, a new process to manufacture it, and a new supply chain to feed that process and distribute the product.

To keep costs low and increase speed to market, IBM chose a modular product design with a modular supply chain design, built around major components furnished by two virtually unknown companies: Intel and Microsoft. By 1998, the fast-evolving personal computer had gone through seven microprocessor generations: 8088, 286, 386, 486, and Pentium I, II, and III. Still a powerful, profitable, and influential company by the standards of the computer industry, IBM had nonetheless been far outdistanced by its two hand-picked suppliers, who had taken the lion's share of the profits and industry clout that flowed from IBM's standard-setting product. IBM's suppliers also won the allegiance of millions of customers who came to care far more about the supplier's logo—"Intel Inside" or "Windows 95"—than about the brand name of the company that assembled the components and shipped the final product. The power in the chain had shifted, as had the financial rewards.

The IBM-Intel-Microsoft saga provides a rich set of lessons from the fruit flies: When designing your supply chain, whatever your industry, beware of the phenomenon of "Intel Inside." Furthermore, understand that make vs. buy decisions should not be made primarily on which supply option is a little bit cheaper or a little bit faster to market. Rather, supply chain design needs to be recognized as a strategic activity that can determine the fates of companies and industries—and of profits and power. Finally, we observe that the element of the supply chain that controls the chain can shift over time: In computers, it was first the original equipment manufacturer (OEM) and later the component makers who wielded the most clout in the chain.

These lessons apply equally well to slower clockspeed industries such as automobiles. The role of electronics subsystems in cars, for example, has evolved dramatically since the 1960's, when little more than a vehicle's lights, radio, windshield wipers, and starter motor were electrically controlled. Today, the dollar value of a car's electronics is overtaking the value of its steel body, for example, and the electronic system rivals the steel body as one of the most important subsystems. In fact, virtually all the features that affect customers' perceptions of a vehicle are—or soon will be—mediated by electronics. Those features include acceleration, braking, steering, handling, and seating, as well as the communication, information, and entertainment systems.

Of course, the evolution of the importance of electronics in the car has profound implications for the relative power and value of various players in the automotive value chain. The relatively slow clockspeed of the automotive landscape gives industry players some time for deliberation and choice. But there may come a day when customers choose automobiles based on whether it sports a logo saying "Denso Inside," "Delphi Inside," or "Nokia Inside" rather than by the name of the company that stamped and welded the sheet metal.

Supply Chain Structural Dynamics Along the Double Helix

Another set of insights from the computer industry helps us to understand the patterns of evolution in supply chain structures. In the 1970s and the early 1980s the computer industry's structure was decidedly vertical. The three largest companies, IBM, Digital Equipment Corporation (DEC), and Hewlett-Packard, were highly integrated, as were the second tier of computer makers. Companies tended to provide most of the key elements of their own computer systems, from the operating system and applications software to the peripherals and electronic hardware, rather than sourcing bundles of subsystem modules acquired from third parties.

In this era, products and systems typically exhibited closed, integral architectures. That is, there was little or no interchangeability across different companies' systems. DEC peripherals and software, for example, did not work in IBM machines, and vice versa—so each company maintained technological competencies across many elements in the chain.

IBM had significant market power during that time and was very profitable. By holding to its closed product architecture, the company kept existing customers hostage—any competing machine they bought would be incompatible with their IBMs. At the same time, Big Blue emphasized the value of its overall systems-and-service package, determined to stave off competitors who might offer better performance on one or another piece of the package.

In the late 1970s, IBM faced a challenge from upstart Apple Computer. IBM's competitive response, the PC, catalyzed a dramatic change throughout the industry, which quickly moved from a vertical to a horizontal structure. The dominant product was no longer the IBM computer, but the IBM-compatible computer. The modular architecture encouraged companies large and small to enter the fray and supply subsystems for the industry: semiconductors, circuit boards, applications software, peripherals, network services, and PC design and assembly.

A single product/supply chain decision (by a dominant producer) triggered a momentous structural shift—from a vertical/integral industry structure to a horizontal/modular one. The universal availability of the Intel and Microsoft subsystems led dozens of entrepreneurs to enter the personal computer business with IBM-compatibles. The modular (mix-and-match) architecture created significant competition within each segment of the horizontally structured industry.

In this industry, so recently organized along monolithic, vertical lines, there now appeared a spate of separate sub-industries—not only for microprocessors and operating systems, but for peripherals, software, network services, and so on. Within each of the categories, new businesses emerged, making it easier and easier for a computer maker to shop around for just the right combination of subsystems.

On balance, this spread of competition was a healthy development for the industry and for computer buyers, but certainly not for IBM shareholders, who saw their company lose about $100 billion in market value between 1986 and 1992. Some observers have speculated that this model of horizontal/modular competition, which also evolved in telecommunications during the 1990s, might be the new (and permanent) industrial structure for many industries. However, further examination suggests that the horizontal/modular structure may also prove to be quite unstable—as unstable as the vertical/integral structures that give birth to them.

Why might the horizontal/modular supply chain structure be short-lived? Let's look again at the fruit flies in the PC industry.

Modular industry and supply chain structures tend to create fierce, commodity-like competition within individual niches. Such competition keeps the players highly focused on their survival. However, over time, a shakeout typically occurs, and stronger players—those that manage to develop an edge in costs, quality, technology, or service, for example—drive out weaker ones. Once a firm is large enough to exert some market power in its segment, it sees the opportunity to expand vertically as well. Microsoft and Intel, each of which came to dominate their respective segments, have exhibited this behavior. Intel expanded from microprocessors to design and assembly of motherboard modules, making significant inroads into an arena typically controlled by the systems assemblers such as Compaq, Dell, and IBM. In addition, with each new microprocessor generation, Intel added more functions on the chip (functions that applications software suppliers traditionally offered), thereby making incursions into the software applications segment as well.

In the case of Microsoft, dominance in PC operating systems has led to the company's entry into applications software, network services, Web browsers, server operating systems, and multimedia content development and delivery. In short, Microsoft looks a little bit more each day like the old IBM—attempting to dominate increasingly large slices of the overall industry and earning monopoly-like profits in the process. Microsoft's ability to integrate across the

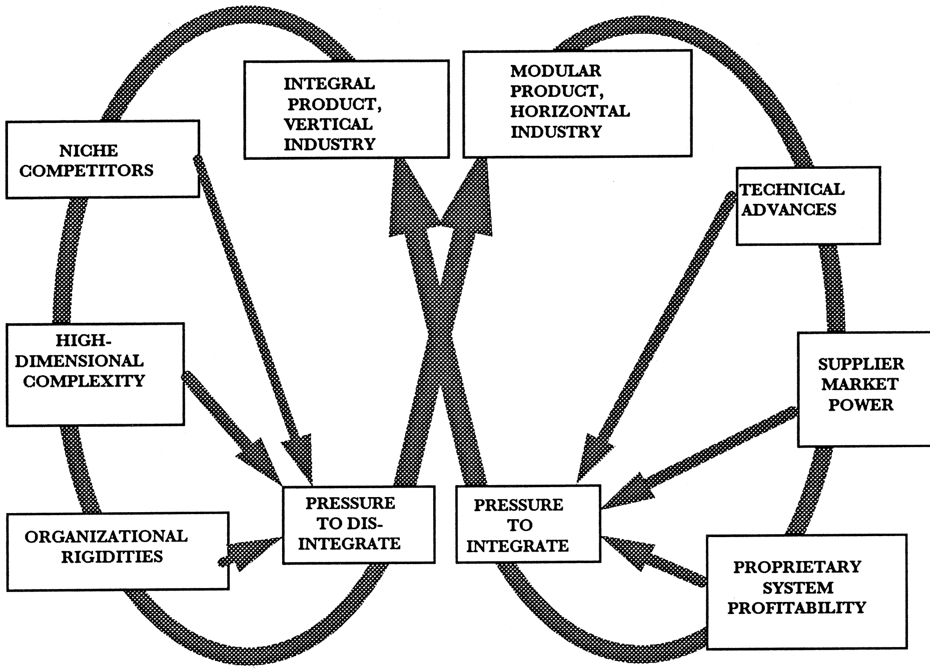

FIGURE 1. The Double Helix Illustrates the Oscillation in Supply Chain Structure Between Vertical/Integral and Horizontal/Modular. Adapted from "Is the Make-Buy Decision Process a Core Competence?" by Charles H. Fine and Daniel Whitney, in Moreno Muffatto and Kulwant Pawar (eds.), *Logistics in the Information Age,* Servizi Grafici Editoriali, Padova, Italy, 1999, pp. 31–63.

segments is particularly vivid (to both competitors and regulators) because its market share is so large and information technology is so flexible.

The computer industry of the 1980s and 1990s therefore illustrates an entire cycle of supply chain structure evolution (Figure 1). Consider the dynamic forces at work: When the industry structure is vertical and the product architecture is integral, the forces of disintegration push toward a horizontal and modular configuration. These forces include:

1. The relentless entry of niche competitors hoping to pick off discrete industry segments.

2. The challenge of keeping ahead of the competition across the many dimensions of technology and markets required by an integral system.

3. The bureaucratic and organizational rigidities that often settle upon large, established companies.

These forces typically weaken the vertical giant and create pressure toward disintegration to a more horizontal, modular structure. IBM, it might be argued, had all these forces lined up against it: constant pressure from niche entrants, particularly in software and peripherals; competitors who took the lead in some technological segments (Intel's invention of the microprocessor, for example); and the many layers of bureaucracy that grew up as IBM expanded its workforce to almost half a million employees at its peak in the 1980s.

On the other hand, when an industry supply chain has a horizontal/modular structure, another set of forces push toward more vertical integration and integral product architectures. These forces include:

1. Technical advances in one subsystem can make that the scarce commodity in the chain, giving market power to its owner.

2. Market power in one subsystem encourages bundling with other subsystems to increase control and add more value.

3. Market power in one subsystem encourages engineering integration with other subsystems to develop proprietary integral solutions.

We therefore learn another important lesson about the evolution of supply chain structures: They should not be expected to be stable. Instead one should expect supply chain structures to cycle between integral/vertical and horizontal/modular forms. Furthermore, the speed with which the structures cycle is influenced by the clockspeed of the industry. In the computer industry, less than two decades transpired before a full cycle had come to completion. In the auto industry, however, the current modularization trends are closing a cycle begun in the first decade of this century.

Clockspeed Drivers and Outsourcing for Speed

Studying the evolution of fruit fly industries provides other insights into supply chains. For example, many in the supply chain community are familiar with the bullwhip principle (i.e., the "first law of supply chain dynamics"), which states that the magnitude of demand volatility a company faces increases the farther upstream it resides in the supply chain. Thus, personal computer manufacturers experience less demand volatility than semiconductor manufacturers, who, in turn, experience less demand volatility than their semiconductor equipment suppliers.

Study of clockspeeds in the fruit fly industries has led me to posit what I call clockspeed amplification—"the second law of supply chain dynamics." This hypothesis states that the industry clockspeed a company faces increases the farther downstream it is located in the supply chain. Thus, personal computer manufacturers experience faster clockspeeds (e.g., shorter product life cycles) than semiconductor manufacturers, who, in turn, experience faster clockspeeds than the semiconductor equipment suppliers.

This insight helps us understand the unprecedented clockspeeds experienced in our economy in the 1990s and helps us peer into the future as well. In particular, when some core technology far upstream in the value chain experiences an increased clockspeed, the rapid rates of change experienced there accelerate as they cascade down the supply chain. So the "killer technology" rates[2] experienced this decade in semiconductors and fiber optic cable, for example, have driven hyper-fast clockspeeds in the information and communication industries, which, in turn, contribute to the supply chains of virtually every other industry on the globe.

If rapid rates of technological innovation are clockspeed accelerators, what are the decelerators? One key clockspeed damper is system complexity. Dell is able to come out with new computer models much more frequently than Lockheed-Martin turns out new fighter jets because a fighter jet is a far more complex system than a PC. Modularizing a product's architecture breaks it down into simpler subsystems and often enables a faster development pace.

Within the defense industry, for example, complex computer systems for signal and image processing on aircraft, surface ships, and submarines have been modularized from the other subsystems and successfully outsourced to Mercury Computer Systems. The Aegis naval defense systems, recently in the news with the potential Taiwanese export order, the unmanned spy planes flying over Bosnia and Kosovo, and the sonar systems in much of the Navy's submarine fleet, are all equipped with Mercury's specialized computers.

Such modularization and outsourcing not only significantly reduces the product development times for the defense suppliers but eases the way for frequent and profitable upgrades as more powerful imaging technology is developed. As another example, makers of complex

[2] For more on this theme, see "Biography of a Killer Technology: Optoelectronics Drives Industrial Growth with the Speed of Light," by Charles Fine and Lionel Kimerling, Special Report for the Optoelectronics Industry Development Association, June, 1997. This paper can be downloaded from http://www.clockspeed.com).

medical imaging systems such as General Electric, Marconi, Philips, and Siemens have also outsourced imaging computer systems to Mercury Computer to speed their development cycles and improve the performance of their machines. Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) systems have advanced as rapidly as almost any technology in the medical field, leading to on-the-spot diagnoses in many hospitals. By outsourcing Mercury's advanced technology, these suppliers have cut their time to market and stolen a march on some less resourceful competitors.

Finally, in the telecommunications domain, wireless service providers such as Ericsson, Lucent, Motorola, and Nortel may soon find that outsourcing opportunities such as inserting Mercury Computer's signal processing technology may double or triple base station capacity and provide the higher data rates needed by the advancing Internet-based applications. Having wireless wideband early is likely to determine the leaders in this rapidly developing field and outsourcing the technology could be the answer for many of today's suppliers. OEM firms will have to weigh the merits of speed and technology innovation from outsourcing against the risks of dependence on an outside firm for a key technology.

Implementation: Three-Dimensional Concurrent Engineering

Stimulated by the success of superior Japanese manufacturing methods, many Western manufacturers in the 1980s worked overtime to benchmark remarkable companies such as Toyota and Sony. By the early 1990s, many had achieved a huge breakthrough in their understanding of competitive advantage through manufacturing. A large portion of the learning came under the heading of concurrent engineering (CE) or design for manufacturing (DFM). Managers realized that they could not achieve improved manufacturing performance solely, or even primarily, by concentrating on the factory; rather, they had to focus on concurrently designing the product and the manufacturing process—that is, designing the product for manufacturability.

Three-dimensional concurrent engineering (3-DCE) extends this concept from products and manufacturing to the concurrent design and development of capabilities chains. In particular, once one recognizes the strategic nature of supply chain design, one feels almost compelled to integrate it with product and process development.

The good news is that the implementation of 3-DCE does not require radical surgery in organizational processes. This news should come as a relief for the many who have reengineered and have been reengineered by managers who insist they must below up their existing organizations in order to create necessary change.

Instead of such a radical solution, even as an antidote to it, I advocate leveraging one basic organizational methodology, variously referred to as concurrent engineering, the product development process, design-build teams, or integrated product teams (IPTS), as the core of the implementation process for three-dimensional concurrent engineering.

Figure 2 illustrates several interactions across product, process, and supply chain development activities. Where the three ovals overlap we locate those activities that need to be undertaken concurrently, either bilaterally or collectively, among the three functions. This diagram further illustrates that not all of the activities undertaken within any of the three functions need to be performed in conjunction with members of the other groups. That is, not all work must take place in IPTS. Rather, IPTS would concern themselves only with tasks in which activities of two or all three functions overlap.

Figure 2 attempts to capture visually many of the ideas of 3-DCE. One can consider how architecture decisions are made through discussions within and across the product, process, and supply chain organizations. A further refinement of the overlapping areas of concurrency across product, process, and supply chain development appears in Figure 3, which also highlights the imperative of concurrency.

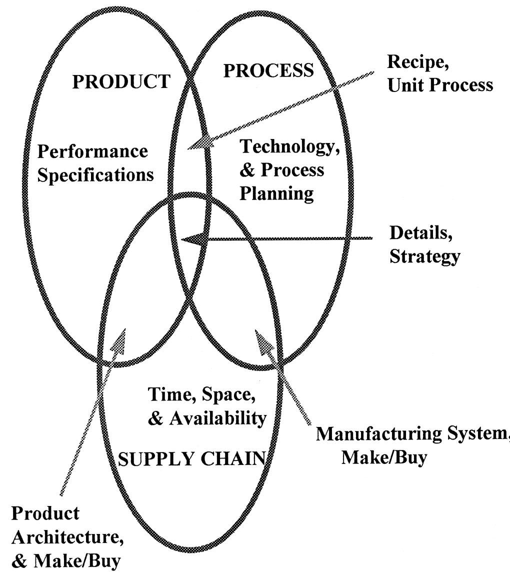

FIGURE 2. Overlapping Responsibilities Across Product, Process, and Supply Chain Development Activities. Adapted from "Architectures in 3-D: Concurrent Product, Process and Supply Chain Development," by Morris A. Cohen and Charles H. Fine, MIT Working paper, August 2000.

This figure divides each of the three developmental areas—product, process, and supply chain—into two sub-activities:

- *Product development* is subdivided into activities of architectural choices (for example, integrality vs. modularity decisions) and detailed design choices (for example, performance and functional specifications for the detailed product design).
- *Process development* is divided into the development of unit processes (that is, the process technologies and equipment to be used) and manufacturing systems development—decisions about plant and operations systems design and layout (for instance, process/job shop focus vs. product/cellular focus).

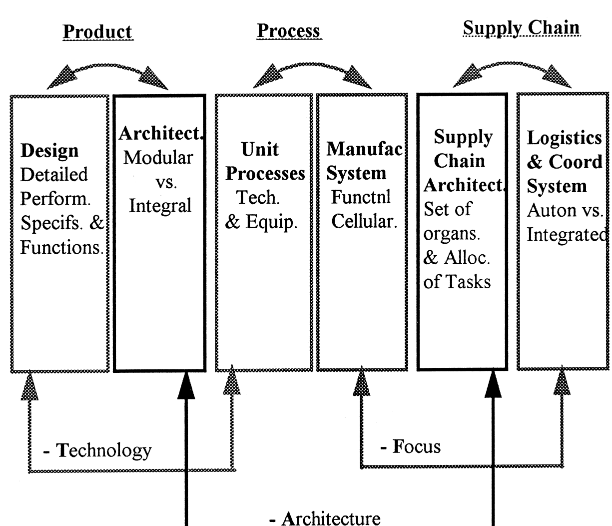

FIGURE 3. The 3-DCE Concurrency Model. Adapted from "Architectures in 3-D: Concurrent Product, Process and Supply Chain Development," by Morris A. Cohen and Charles H. Fine, MIT Working paper, August 2000.

- *Supply chain development* is divided into the supply chain architecture decisions and logistics/coordination system decisions. Supply chain architecture decisions include decisions on whether to make or buy a component, sourcing decisions (for example, choosing which companies to include in the supply chain), and contracting decisions (such as structuring the relationships among the supply chain members). Logistics and coordination decisions include the inventory, delivery, and information systems to support ongoing operation of the supply chain.

The next two cases, from Intel and Chrysler, further illustrate these ideas.

Intel

In an era and industry of unprecedented clockspeed acceleration, Intel Corporation has risen about as quickly as any corporation in history as a major manufacturer. Most of Intel's growth to a $30+ billion corporation occurred over less than a decade, a period during which the company built highly capital-intensive factories and introduced new products at a blistering pace. Much of its success in keeping competitors at bay during the period of explosive growth resulted from the ability to execute new product and process development with many new suppliers at breakneck speed. In short, Intel proved to be a master of fast-clockspeed 3-DCE.

Given the complexity of the underlying technologies, we can gain a valuable understanding of how Intel simplified the daunting 3-DCE challenges it faced. Its approach offers lessons for any company contemplating a shift to three-dimensional concurrent engineering. Intel's microprocessor product families—popularly known as the 286, 386, 486, and Pentium processors—resulted from a massive product development process, involving hundreds of engineers and scientists working over multiple sites and multiple years.[3]

Historically in the semiconductor industry DRAM (dynamic random access memory) products absorbed the lion's share of new process technology investment. Each new generation of product—64 Kb RAM, 256 Kb RAM, 1 Mb RAM, and so forth—was launched on an all-new generation of manufacturing process (typically denoted by the smallest line-width on the integrated circuits). Thus, for a DRAM manufacturer, launching a new product meant simultaneously launching a new process—always a complex affair. Through most of the 1980s, the Japanese semiconductor companies concentrated on DRAM design and production, exploiting their skills in precision clean manufacturing. The Japanese tended to be the process technology leaders into each new smaller line-width process generation.

By the early 1990s, however, Intel found itself in the position of needing new processes (for example, more metallization layers) in advance of the DRAM industry's needs or its willingness to invest in such processes. As a result, the DRAM makers no longer unequivocally drove process development. Having emerged as the 800-pound gorilla of the industry in the early 1990s, Intel had to learn to be a process technology leader and to develop systems whereby it could continue to improve process technology while accelerating its pace of product development.

Intel crafted a brilliant 3-DCE strategy that used product/process modularity to reduce significantly the complexity of the company's technical challenge. Throughout the 1990s, the company launched each new microprocessor generation on the "platform" of an old (line-width) process. Alternately, each new process generation was launched with an "old" product technology. For instance, Intel introduced its i486 chip on the one-micron process developed for the i386 chip, a process that had already been debugged. Following the success of this process, Intel created the .8-micron process, which was first tried on the now-proven i486 chip. Next, it launched the Pentium chip on the proven .8-micron process before moving it over to the new .6-micron process. Leveraging this system of alternating product and process

[3] Sean Osborne, *Product Development Cycle Time Characterization Through Modeling of Process Iteration*, MS thesis, MIT-LFM program, 1993.

launches, Intel created almost perfect modularity between product and process, a marriage that reduced dramatically the complexity of any given launch. Reducing the complexity of concurrent engineering has, of course, been one of the keys to Intel's success in its hyperfast-clockspeed industry.

When viewed through the lens of the third dimension, however, Intel's link between process and supply chain is much more integral. That is, process development goes hand in glove with supply chain development. Especially by the mid-1990s, when Intel needed to drive new process technologies rather than adapt technologies that had already been debugged to a great extent by the DRAM manufacturers, Intel found itself nurturing start-up companies that were just developing the advanced technologies necessary for the next-generation processes Intel needed. As a result, Intel fostered integral development of new processes and new suppliers to support those processes.[4]

Chrysler

In some ways, Chrysler of the 1990s could be likened to Compaq of the 1980s. Through a modular product and supply chain strategy, each company managed to upset the advantages of much larger rivals and to trigger a chain reaction of events that altered dramatically the structure of the entire industry.

Through the lens of 3-DCE, we can see both the strengths and potential weaknesses of Chrysler's strategy more clearly. By outsourcing the development and integration of numerous automotive subsystems, Chrysler cut dramatically the total time and cost required to develop and launch a new vehicle. The company has effectively exploited the opportunities from this approach, as described earlier.

Because Chrysler, in contrast to many of its competitors, is so quick from concept to car, the company has enjoyed a high rating with consumers on the most desirable designs and features. Such designs allowed Chrysler to charge premium prices with minimal rebating throughout much of the 1990s.

Conclusion

I believe that the increased interest in supply chain design as a strategic precursor to supply chain management will only increase in the decade to come as industry clockspeeds continue to accelerate, and the half-lives of many capabilities in our existing supply chains need replacement and/or upgrading. Furthermore, I believe that analyzing the dynamics of supply chains in the fast-clockspeed fruit fly industries can provide insights to companies in all industries for assessing strategic options in a rapidly evolving industrial world.

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[4] I am indebted to Randy Bollig, Intel's director of corporate capital acquisition in the late 1990's, for these insights into Intel's supplier development system.