MAKE-BUY DECISIONS IN THE FACE OF RADICAL INNOVATIONS

by

Robert K. Perrons

Fitzwilliam College

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

University of Cambridge

Department of Engineering
Institute for Manufacturing

July 2004

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Robert K. Perrons
lifetime e-mail: perrons@alum.mit.edu

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July 2004

Summary:

Some research in the area of make-buy decisions for new technologies suggests that it is a good idea for a company to pursue a fairly rigorous "make" policy in the early days of a potentially disruptive innovation. Other studies prescribe exactly the opposite, promoting instead a "buy" strategy. This lack of convergence points to the fact that the scheme of categorization used to analyze make-buy decisions in the face of radical innovations is not yet complete. Accordingly, this thesis builds upon prior work on make-buy decisions and disruptive technologies, and constructs two new hypotheses by introducing evidence from research in the areas of (1) supplier relationships and (2) industry clockspeed.

Using a three-phase research design involving both case studies and a survey, this research shows that close relationships between customer firms and principal suppliers that are built on trust and personal relationships do not play an important long-term role in the development of radical innovations. Thus, while previous research in this area underlines the value of these relationships during the day-to-day operations of a business, this evidence draws into question whether they are helpful in the face of a radical innovation.

The results also show that an industry's clockspeed has no significant bearing on the success or failure of any particular make-buy strategy for a radical innovation. Because many of the prescriptive frameworks and strategic formulas put forward in the literature for make-buy decisions involving radical innovations are based on observations from fast clockspeed industries, this conclusion effectively broadens the potential applicability of prior research in this area.

PREFACE

Except for commonly understood and accepted ideas, or where specific reference is made, the work reported in this dissertation is my own and includes nothing that is the outcome of work done in collaboration. No part of the dissertation has been previously submitted to any university for any degree, diploma, or other qualification.

This dissertation consists of approximately 52,000 words, and therefore does not exceed the 65,000 word limit put forth by the Degree Committee of the Department of Engineering.

Robert K. Perrons
Cambridge
July 2004

ACKNOWLEDGEMENTS

Let's face it: there's a lot about the life of a PhD student that leaves room for improvement. You sit in a basement reading innumerable journals about topics that virtually no one cares about. You work long, thankless hours writing a document that almost no one will read. You earn far less money than your chronological peers, and every indication suggests that this trend will continue unabated well after you finish your degree. It is therefore both rational and reasonable for any doctoral candidate to wonder, "Why am I doing this?" The answer to this question wasn't clear to me at the outset of my Cambridge career.

But it is now. The magic of this process largely pivots on the people with whom you are trapped in the dimly lit basement, and who understand your destitution. They are quite obviously far too smart to earn so little money and to receive so little recognition—but they do it anyhow. And they love it. Moreover, their love of the craft makes *you* love it. Officemates like Oliver Hugo, Johannes Schmitz, Kim Hua Tan, Jannis Angelis, and Scott Wilson taught me more by osmosis than any book I will ever read, and for this I am eternally grateful. Ditto for the amazing friends I have made elsewhere in the Institute: Seena, Ryan, Jon, Michael, and Finbarr.

There are occasions, too, when the dark realities of the PhD life cause the original question to shift to, "Why am I doing this *here*?" My answer to this one is alarmingly easy: Dr. Ken Platts. It's doubtful that any supervisor could've done more, been fairer, or made this process more enjoyable. Few mentors are good enough to justify a PhD program an ocean away from one's home—but Ken certainly is.

And then there's Shannon. The only thing more frustrating than putting up with the diminished lifestyle and long hours is putting up with it in the name of someone else's ambition. Thank you for sharing my dream. I look forward to returning the favour over and over again.

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LIST OF ABBREVIATIONS AND ACRONYMS

AMD	Advanced Micro Devices
AmEx	American Express
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CD	Compact Disc
CEO	Chief Executive Officer
CFD	Computational Fluid Dynamics
CFO	Chief Financial Officer
CISC	Complex Instruction Set Computer
COO	Chief Operating Officer
CO_2	Carbon Dioxide
CPU	Central Processing Unit
CTE	Coefficient of Thermal Expansion
C4	Controlled Collapse Chip Connect
DEC	Digital Equipment Corporation
DVD	Digital Video Disc
EM	Expectation Maximization
GDP	Gross Domestic Product
GE	General Electric
GM	General Motors
IBM	International Business Machines
IP	Intellectual Property

MCAR	Missing Completely At Random
MHz	Megahertz
m^3	Cubic Metres
NAICS	North American Industry Classification System
NCR	National Cash Register
NPD	New Product Development
PC	Personal Computer
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
ROI	Return on Investment
R&D	Research & Development
SIC	Standard Industrial Classification
SME	Small- and Medium-Sized Enterprise
TEG	Triethylene Glycol
TSMC	Taiwan Semiconductor Manufacturing Company
UK	United Kingdom
UMIST	University of Manchester Institute of Science and Technology
US	United States
3M	Minnesota Mining and Manufacturing

Chapter 1: Introduction

The principal goals of this thesis are four-fold. First, it will examine why companies prefer to produce some inputs internally while opting to buy others from suppliers, and it will consider how radical innovations can impact make-buy decisions. Second, towards expanding the existing system of classification for radical innovations, this study will put forward two new hypotheses by introducing ideas from the areas of (1) supplier relationships and (2) industry clockspeed. Third, it will test the hypotheses using both quantitative and qualitative research methods. Fourth, the results of the investigation will be translated into strategic insights that can contribute to how decision-makers in industry manage potentially radical innovations.

To these ends, this chapter will begin by establishing what make-buy decisions are and by demonstrating how they can be dramatically affected when an innovation is introduced into the marketplace. Finally, this chapter will explain the structure of the thesis and provide a rough description of each chapter's contents.

1.1 What Are Make-Buy Decisions?

As Fine & Whitney (1996) suggest, many of today's products "are so complex that no single company has all the necessary knowledge about either the product or the required processes to completely design and manufacture them in-house. As a result, most companies are dependent on others for crucial elements of their corporate well-being" (p. 1). Most firms rely to varying degrees on outside suppliers for components, inputs, or know-how (Doz & Hamel, 1997; Wilkinson & Young, 2002). This reality of modern business is largely a result of the fact that "organizations cannot be world class in everything they do as core competence and therefore must ally to other capabilities to satisfy their customers" (Macbeth & Chan, 1994, p. 19).

But what tasks and functions should be outsourced—that is, what inputs and functions should a company produce internally and which ones should it buy from outside suppliers? And for those inputs that the company chooses to buy from other firms, what type of relationship should be developed with the suppliers? The answers to these questions are known as "make-buy decisions."

A single make-buy decision[1] in and of itself may not seem to be of great consequence to a company. Among the many components and services that a firm uses to generate revenues, relatively few are singularly of critical importance to the firm's immediate survival or success. But the aggregate of these decisions effectively defines the scope of what a company is and is not doing. In other words, the "resolution of these questions defines the boundary of the firm" (Anderson & Weitz, 1986, p. 3). Make-buy decisions are therefore an important aspect of many companies' strategic planning processes (Gertner & Knez, 2000; McIvor & Humphreys, 2000). And there is evidence that these issues are perceived to be growing in importance as time goes on. As Quinn (1999) points out, "the decision on whether and how to outsource is steadily moving up the organization to the CFO, COO, and CEO levels"[2] (p. 11).

Moreover, the relevance and importance of make-buy decision-making processes is multiplied by the fact that many firms' outsourcing strategies tend not to remain rigidly in place forever. Instead, a company's make-buy judgments ought to be re-visited from time to time in order to keep the firm's outsourcing policy in-step with shifts in markets, demand, or government policy (Cáñez, 2000; Fine & Whitney, 1996; Probert, Cáñez, & Platts, 2001). Harrigan (1984) makes this same observation, and suggests that a firm's make-buy decisions have "to change over time, as industry conditions change or as firms' needs to control adjacent industries tightly change" (p. 642).

But shifts in markets, demand, or government policy are by no means the only sources of changes that might noticeably shape a company's make-buy judgments. New technologies can also significantly influence the structure of an entire industry, and how a firm chooses to handle a

[1] The topic of make-buy decisions is frequently referred to in the literature by aliases other than this one. "Vertical integration," "outsourcing," "sourcing," and "make or buy" are for the most part variations in terminology that principally point to the same set of issues. All of these terms are used interchangeably throughout this thesis.

[2] These abbreviations stand for Chief Financial Officer, Chief Operating Officer, and Chief Executive Officer, respectively.

novel product or process can play a key role in its overall competitive strategy (Porter, 1985, p. 176). Accordingly, one other major instigator of change in make-buy policies that companies in many different industries routinely deal with is the introduction of radical innovations (Fine, Vardan, Pethick, & El-Hout, 2002).

1.2 The Effect of Innovation on Make-Buy Decisions

History is rife with examples of how ages-old methods and processes were abruptly displaced in the business world by new ideas and techniques that did not exist only a few years before. And just as these innovations had a profound effect on the society and economy of the day, they also brought about a dramatic shake-up in the industries around them. In fact, it has been estimated "that leadership changes hands in about seven out of ten cases" (Utterback, 1994, p. 162) when major technological discontinuities occur. Indeed, as Utterback (1994) contends, innovation "is at once the creator and destroyer of industries and corporations" (p. xiv of introduction). Cooper & Schendel (1976) add that "[f]ew environmental changes can have such important strategic implications" (p. 61).

If make-buy decisions are an integral component of any firm's overall strategy, and if disruptive technologies do frequently reshape the strategic landscape of the industries into which they are introduced, then it follows that make-buy decisions may also be sensitive to new technologies. And history does indeed suggest that this is the case. There have been several instances over the years in which firms' make-buy strategies were significantly amended after an innovation was brought into the marketplace. These changes were by no means confined to a particular industry. What follows are examples of how disruptive technologies substantially altered make-buy decisions on a fundamental level within the Swiss watch industry, the US bicycle sector, the personal computer market, and in the software distribution industry.

1.2.1 The Swiss Watch Industry

Kumpe & Bolwijn (1988) point out that the generations-old Swiss watch industry used to be quite different from what it is today. The mechanical watches made by Swiss craftsmen required an impressive number of meticulously manufactured and assembled parts. The job of designing and assembling these components was typically relegated to a large number of small, independent suppliers.

But the situation changed quite dramatically with the advent of the Japanese watch industry. Using quartz crystals as a means for measuring time in lieu of the more traditional mechanical designs espoused by the Swiss manufacturers, Japanese watch manufacturers quickly gained a large portion of the market at the expense of their Swiss counterparts. The Swiss were very much at a loss as to how to respond to this new threat. The new quartz technology represented a dramatic departure from the status quo, and many suppliers in the Swiss watch industry either could not or would not keep pace with this change in the market.

The solution to this precipitous decline in the Swiss watch industry was devised by Swatch, which has grown in profile over the years to become a key player in the market. Instead of using the time-honoured supply chains that had been a fundamental feature of the industry for generations, Swatch elected to bring in-house all the steps of the production chain from components to final assembly. This re-integration of the value network allowed Swatch to transform the Swiss watch from a mechanical wonder constructed by many firms to a marketing phenomenon that could be sold on the basis of brand recognition and fashion.

1.2.2 The US Bicycle Sector

Fine (1998) describes how, in 1905, the US bicycle industry essentially consisted of only 12 companies. At the time, bicycles were not regarded as a serious means of transportation, but rather as mere playthings for children. Each bike manufacturer's designs were relatively banal and almost indistinguishable from those of its competitors. The suppliers who provided the components wielded a tremendous amount of power in the supply chain, and steadfastly refused to invest in any significant innovations because "they believed that the public would not pay more for 'children's toys'" (Fine, 1998, p. 52).

Frustrated by the unwillingness of US bicycle component suppliers to invest in the development and improvement of bicycle technologies, and believing that there was a yet-undiscovered market for higher end bicycles that were not children's toys, F. W. Schwinn set out on an exploratory tour of European bicycle manufacturers. When he came back, he brought with him a host of novel and progressive bicycle innovations that had not yet been adopted by markets on the other side of the Atlantic. These ideas inspired Schwinn to come up with many new ones of his own, for which he was granted over 40 patents during the 1930s. Such innovations as the "Super

Balloon Tire Bicycle," the "Aero Cycle," and the built-in "Cycle Lock" brought about a quantum leap in the industry.

Instead of outsourcing the production of the parts for his bicycles as had been done for decades, though, Schwinn decided instead to keep many of these functions in-house. If the company's existing suppliers could not keep up with the new innovations, or if they could not work within the cost estimates put forth by Schwinn, then he was more than prepared to resort to vertical integration and make the part in-house. This strategy—that is, vertically integrating any and all functions that the supply network would not grow to accommodate—allowed Schwinn's company to break free from the static deadlock among the other 11 firms in the industry. The firm's markedly different approach to outsourcing contributed significantly to its leading role in the industry, a position that the company held until the 1970s.

1.2.3 The Personal Computer Market

The evolution of the personal computer (PC) market is another scenario in which technological breakthroughs brought about a major overhaul of an industry's make-buy decisions (Fine, 1998). Throughout much of the 1970s, computer companies like IBM, DEC, and Hewlett-Packard were for the most part vertically integrated. The industry consisted principally of a small number of large firms that were capable of internally designing and producing almost all of the major components and supporting elements of a computer system, from the microprocessors to the operating systems to the peripherals and application software.

But the release of Apple's home computers in the late 1970s changed the industry dramatically. Advances in computer engineering and miniaturization made it possible to create a desktop computer that could perform functions that, only a few years before, would have required a computer the size of an entire room. To respond to this new threat in a focused and dedicated way, IBM created a standalone PC division.

IBM's senior managers wanted to bring the PC to market in less than a year (Gates, 1996). To achieve this ambitious objective, the division decided to outsource the design and production of the new system's microprocessors to Intel and the operating system to Microsoft. This approach represented a dramatic break from the industry's longstanding tradition of vertically integrating almost every aspect of computer manufacturing. But IBM's component suppliers "historically had lived a miserable, profit-free existence, and the business press widely praised IBM's decision to outsource these components of its PC. It dramatically reduced the cost and time required for development and launch" (Christensen & Raynor, 2003, p. 126). This decision laid the groundwork for a new evolutionary path in the industry, and what was once a tightly vertically integrated value network quickly grew into an army of companies of various sizes that offered semiconductors, circuit boards, applications software, peripherals, and network services.

1.2.4 Internet-Based Software Distribution

Much like the invention of the PC, the dawn of the internet age has shaken up many aspects of the commercial world, and has caused many industries to rethink basic aspects of their business models. The distribution of software is yet another business that is changing dramatically because of the introduction of a radical innovation. Leifer *et al.* (2000) point out that software distribution channels used to work much differently than they do today. Authors of new programs used to sell their products via established companies that had large distribution networks. It was left to the distribution companies to attend to the security of the software—that is, to protect the program so that it could not be reproduced for free.

Jeff Dodge, a senior business manager at Nortel Networks, wondered if this business model was still the most efficient way for authors to reach their customers. Mr. Dodge observed that "[f]ew people who want to see a movie are willing to purchase it outright… but thousands more will put up $3 to rent a videocassette version for a day or two. The same might apply to gaming software, tax preparation programs, and others" (Leifer *et al.*, 2000, p. 95). His solution to this problem was to devise NetActive, a method of encoding software in a way that would allow a customer to use the software only for a specified period of time. After the specified period had elapsed, however, the software would automatically reconnect to the NetActive system and demand more money from the customer.

The NetActive system eventually found appeal among small-scale software publishers. Prior to the introduction of this new technology, these small producers had been consistently squeezed out of prime shelf space in software retail outlets. NetActive's locking technology represented a shake-up of the business model that would essentially reorganize the value chain such that smaller software companies could protect their own customer interface networks without the help of the larger distribution companies. Simply put, smaller players in the industry could elect to "make" in-house some aspects of the distribution networks that they had previously been forced to "buy."

1.2.5 Common Themes Arising from These Examples

There are a few characteristics of the preceding cases that warrant highlighting. First, in each instance, a disruptive new technology brought about a shift in a make-buy policy either within one firm or throughout an entire industry. Second, the scenarios are not confined exclusively to any particular period in history. Some of the discussed upheavals happened nearly 100 years ago; some of them are happening right now. These changes of strategic direction therefore cannot be dismissed as having come from some kind of short-lived anomaly or any kind of idiosyncratic behaviour that was unique to a particular period in time. Third, all of the cases were from industries that are different from one another in many regards. These three characteristics strongly point towards a general theme: no matter when they happen and irrespective of what industry they happen in, radical innovations are capable of dramatically affecting companies' make-buy strategies.

1.3 Structure of the Thesis

As shown in Figure 1.1, this thesis consists of eight chapters. Following the introduction, Chapter 2 establishes the foundation for the investigation by exploring systems of classification that have previously been applied in the technology management literature. The chapter then converges on a definition of "radical innovation" that is applied throughout the rest of the study. Next, Chapter 2 reviews prior research in the area of outsourcing decisions and discusses why companies prefer to produce internally some inputs while preferring to buy others from suppliers. Drawing from the field of technology management, it then considers how radical innovations can shape make-buy strategies, and puts forward two new hypotheses by introducing ideas from the areas of (1) supplier relationships and (2) industry clockspeed.

Chapter 3 discusses the strengths and weaknesses of case study research and survey-based research, and explains why this investigation used both types. Then it explains the three-phase research design applied to this investigation and discusses its limitations.

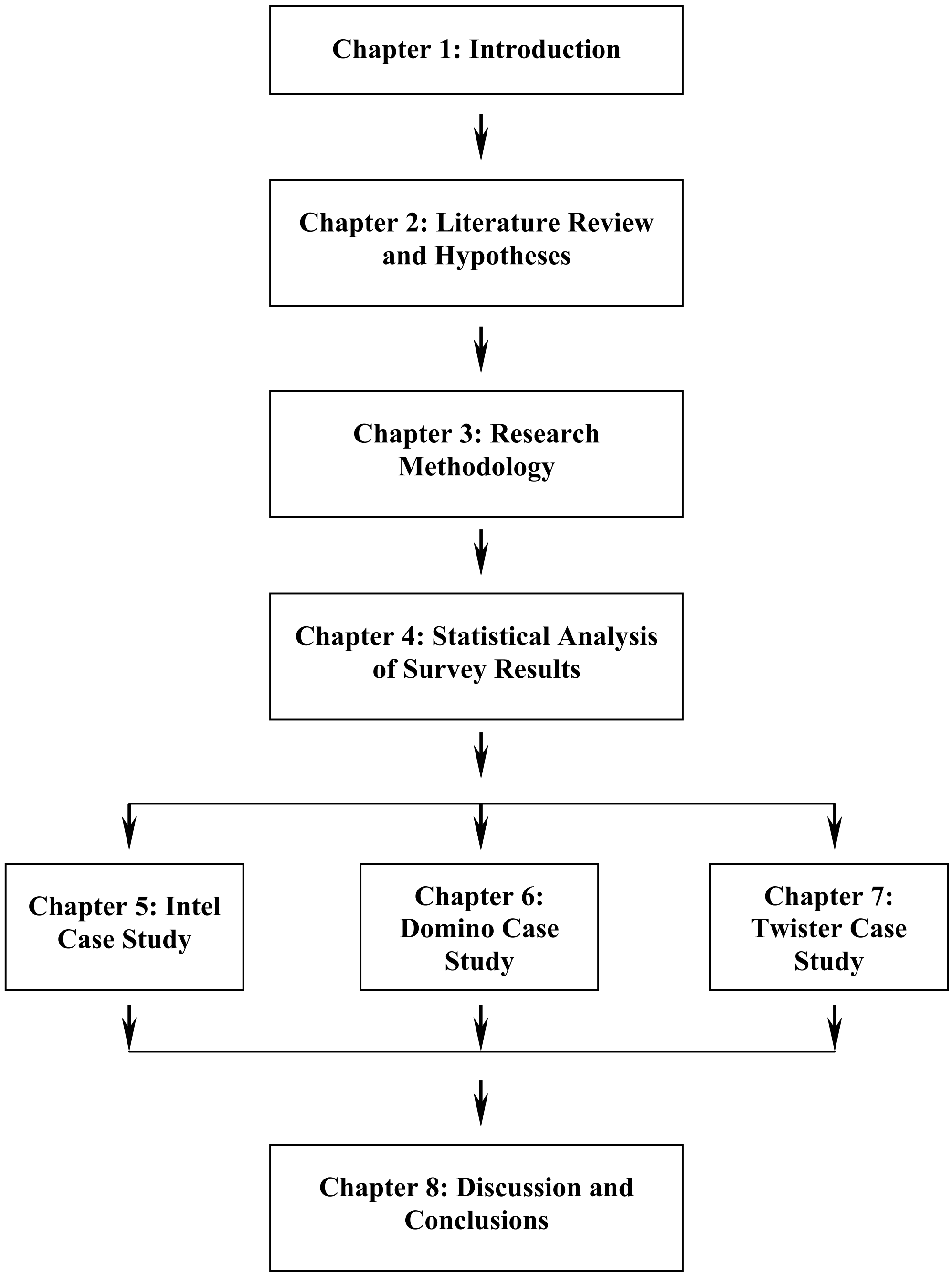

Figure 1.1: Structure of the Thesis

Chapter 4 provides a statistics-based analysis of the data resulting from the survey, and explains the statistical methods and tools that were used in the analysis. Finally, Chapter 4 directly determines whether or not the survey data support the two hypotheses put forward earlier in Chapter 2.

Towards explaining the trends observed in the survey data and establishing causal relationships, Chapters 5, 6, and 7 each discuss a case study involving a firm's make-buy decisions in the face of a radical innovation. Chapter 5 focuses on the Intel Corporation and the transition to organic/C4 packaging in the company's microprocessors. Chapter 6 examines Domino Printing Sciences' expansion into the laser printing market. Chapter 7 discusses the introduction of Twister Cyclone separators into the oil and gas industry. Each of these chapters will shed light on the motives and circumstances that influenced the companies' outsourcing judgments during these periods of transition.

Finally, Chapter 8 will draw together the quantitative and qualitative data presented throughout the thesis, and will determine whether or not this evidence supports the hypotheses developed in Chapter 2. Then Chapter 8 will discuss how these results impact the process of theory building in this research area, and will translate these conclusions into strategic insights that can be used by decision-makers in industry to manage potentially radical innovations. Chapter 8 will conclude by recommending directions for future research in this area.

1.4 Chapter Summary

This chapter began by establishing what make-buy decisions are and by demonstrating how they can be dramatically affected when an innovation is introduced into the marketplace. Then it explained the structure of the thesis and provided a rough description of each chapter's contents. The next chapter will offer a survey of the literature concerning both make-buy decisions and radical innovation, and will construct two new hypotheses by introducing ideas from other fields of research.

CHAPTER 2: LITERATURE REVIEW AND HYPOTHESES

This chapter will begin by exploring the systems of classification that have been applied in the technology management literature, and then converges on a definition of "radical innovation" that will be applied throughout the rest of this investigation. Then it will review prior research in the area of outsourcing decisions and explore why companies prefer to produce internally some inputs while preferring to buy others from suppliers. Next, drawing from the field of technology management, this chapter will consider how radical innovations can shape make-buy strategies. Finally, it will construct two new hypotheses by introducing ideas from the areas of (1) supplier relationships and (2) industry clockspeed.

2.1 Radical Innovation

While Christensen (1997) suggests that "[a]ll firms have technologies" (p. xvi of introduction), Porter (1985) believes that the role of technology is even more fundamental and far-reaching: a "firm, as a collection of activities, is a collection of technologies. Technology is embodied in every value activity within a firm, and technological change can affect competition through its impact on virtually any activity" (p. 166).

Despite the clear importance of technology and innovation to management science, however, researchers in the field have not agreed on solid definitions for these terms (Bolton, 1993; Downs & Mohr, 1976; McDermott, 1999).[3] Nonetheless, some definitional themes and patterns emerge

[3] It must be said, however, that this lack of convergence is considered by some to be typical of management research in general rather than a specific shortcoming of technology management research. Prusak & Davenport (2003) pose the question, "Is there any other field besides management theory where there is such radical fragmentation and lack of defining figures? We think not" (p. 16).

in the literature. The word "technology" is frequently used by management researchers to describe the scientific methods and materials used to achieve some kind of practical end (e.g. Day & Schoemaker, 2000; Hill & Rothaermel, 2003; Roussel, Saad, & Erickson, 1991). But as Bessant & Francis (1999) point out, having ready access to methods and materials "is not the same as making effective use of them" (p. 373). Whereas technology is frequently regarded as a new way of doing things, the word "innovation" is frequently used in a way that also includes the commercialization of technology (e.g. Afuah, 1998; Porter, 1990). In addition to new products or processes, innovation entails the new forms of organization, new markets, and new sources of inputs that support new methods and materials (Pavitt, 1990; Schumpeter, 2000).

Not all innovations are the same, however. To help managers devise appropriate strategies to contend with different varieties of new technologies, management researchers have made considerable progress in characterizing and categorizing different types of innovation. One frequently recurring basis for analysis is the degree of change brought about by an innovation. Some technologies dramatically and obviously change the world around them; others do not. Several studies have accordingly suggested that new technological developments typically fall into one of two categories: those that move things ahead modestly in a way that more or less preserves the status quo, and those that conspicuously disturb various states of equilibrium in an industry.

2.1.1 Definitions Based on Product Performance

Focusing on how customers will receive new technologies in the marketplace and the utility that technological advances will offer to consumers, Christensen (1997) uses the terms "sustaining" and "disruptive" to characterize innovations:

> Most new technologies foster improved product performance. I call these *sustaining technologies*. Some sustaining technologies can be discontinuous or radical in character, while others are of an incremental nature. What all sustaining technologies have in common is that they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued. Most technological advances in a given industry are sustaining in character.
>
> Occasionally, however, *disruptive technologies* emerge: innovations that result in *worse* product performance, at least in the near-term. Ironically, in each of the instances studied in this book, it was disruptive technology that precipitated the leading firms' failure.
>
> Disruptive technologies bring to a market a very different value proposition than had been available previously. Generally, disruptive technologies underperform established products in mainstream markets. But they have other features that a few fringe (and generally new)

> customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use" (p. xviii of introduction).

2.1.2 Characterizations Based on Industry Impact

Looking at the impact that a new technology makes in an industry, Gilbert (2003) suggests that disruptive technologies are those that "create a new, noncompetitive market" (p. 28) that does not infringe on existing markets. Building on this same theme, Bozdogan *et al*. (1998) add that radical innovations can "open whole new applications, markets and even industries" (p. 167). And McDermott (1999) says that radical innovation is "the *creation of a new line of business*, both for the firm and the marketplace" (p. 633). But traditional leaders in an industry do not necessarily have to be displaced for an innovation to be considered radical. Some incumbent firms facing this situation can and do adapt to these dramatic changes. Hill & Rothaermal (2003) point out that "NCR, a dominant enterprise in the era of mechanical cash registers, was able to adapt and ultimately prosper after the arrival of electronics and then digital computing" (p. 257).

2.1.3 Perspectives Based on Product Architecture

Based on observations from the semiconductor photolithographic industry, Henderson & Clark (1990) show that traditional categorizations of innovation "do not account for the sometimes disastrous effects on industry incumbents of seemingly minor improvements in technological products" (p. 9). Towards explaining this phenomenon, they put forward the notion of "architectural innovation." The overall architecture of a product is basically how the components interface and work with one another. An architectural innovation, therefore, is a change in the way that components of a product are linked together. According to this framework, shown in Figure 2.1, a radical innovation is one that overturns core concepts while fundamentally changing how the components of a product are connected.

Henderson & Clark contend that technological shifts of this nature are often difficult for a dominant firm to recognize, and hard to correct as a result. "Since radical innovation changes the core design concepts of the product, it is immediately obvious that knowledge about how the old components interact with each other is obsolete. The introduction of new linkages, however, is much harder to spot. Since the core concepts of the design remain untouched, the organization may mistakenly believe that it understands the new technology" (p. 17).

Core Concepts

Linkages between Core Concepts and Components	Reinforced	Overturned
Unchanged	Incremental Innovation	Modular Innovation
Changed	Architectural Innovation	Radical Innovation

Figure 2.1: Architectural and Component Knowledge Framework [Henderson & Clark (1990, p. 12)]

Many companies' organizational structures are reflected in the architecture of the product they are making and firms frequently organize themselves around their product's primary components, as these are typically the basis for organizing the key subtasks of the firm's design activities (Henderson & Clark, 1990, p. 15). For example, many automotive manufacturers have a powertrain division, an engine team, and a suspension group because each of these organizational bodies corresponds to a principal subassembly of components in a car. Fundamental changes in the architecture of a product may therefore cause critical organizational difficulties inasmuch as the structure of the business and channels of communication would be aligned with the old product architecture.

With smaller commitments to older ways of learning about the environment and organizing their knowledge, new entrants to the market often find it easier to adapt to new types of architecture. Statistical data from the hard disk drive industry suggests that firms entering new market segments tend to do better if they disrupt the industry by introducing an architectural innovation instead of offering innovative component technologies (Christensen, Suárez, & Utterback, 1998).

2.1.4 Definitions Based on Market Linkages

In addition to the market impact brought about by the technology itself, Abernathy & Clark (1985) also suggest that an innovation can be radical in nature if firms' linkages within the marketplace are rendered obsolete. As shown in Figure 2.2, "niche" technologies may leave a manufacturer's technological capabilities perfectly intact, but could cause the company's market capabilities to become useless. Conversely, a technology can be "revolutionary" if it renders obsolete a firm's technological capabilities while making use of its market capabilities. Afuah (1998) explains this perspective by noting that "such market capabilities are important and difficult to acquire, [and] an incumbent whose technological capabilities have been destroyed can use the market ones to its advantage over a new entrant" (pp. 17-18). McDermott (1999) also observes that companies often establish links with outside firms as a means for understanding new markets.

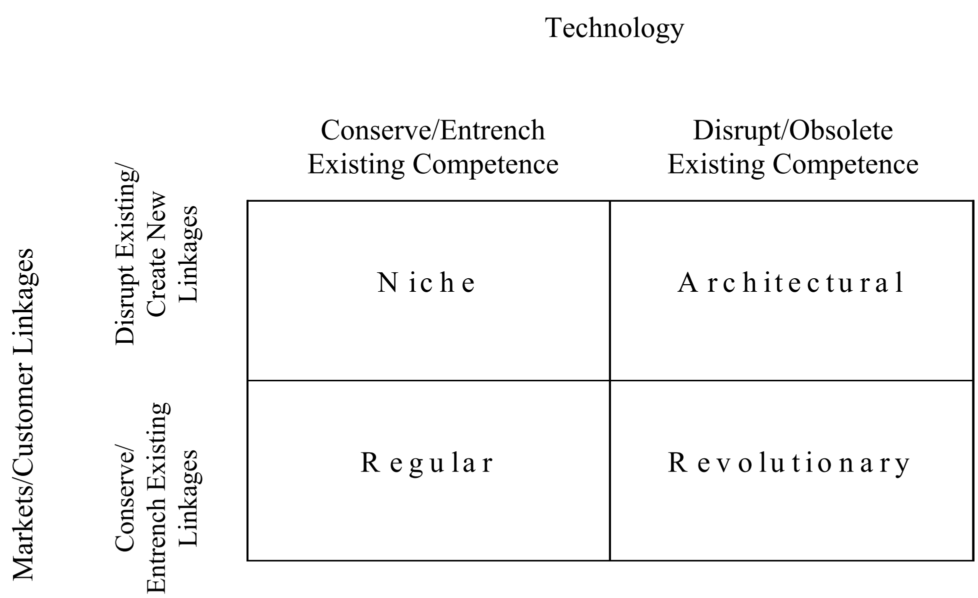

Figure 2.2: Transilience Map of Technological and Market Knowledge [Abernathy & Clark (1985, p. 8)]

2.1.5 Organizational Approaches

Tushman & Anderson (1986) suggest that the impact an innovation has on skills and competences is a key determinant in assessing whether or not an innovation is radical. Using this organizational approach, Tushman & Anderson refer to radical innovations as "competence-destroying" and incremental ones are "competence-enhancing." They explain that competence-destroying discontinuities are "so fundamentally different from previously dominant technologies that the skills and knowledge base required to operate the core technology shift. Such major changes in skills, distinctive competence, and production processes are associated with major changes in the distribution of power and control within firms and industries" (p. 442). By contrast, they define competence-enhancing discontinuities as "order-of-magnitude improvements in price/performance that build on existing know-how within a product class" that are typically "developed through the synthesis of familiar technologies" (p. 442).

Afuah (1998) also bases his definition of radical innovation on the organizational impact a new technology makes on a firm or industry. He suggests that "an innovation is said to be *radical* if the technological knowledge required to exploit it is very different from existing knowledge, rendering existing knowledge obsolete" (p. 15). Because of its focus on organizational changes that can be broadly assessed without an in-depth knowledge of a particular technical area, this definition was used to characterize radical innovations throughout this investigation.

2.2 Make-Buy Decisions

As noted earlier, radical innovations frequently reshape the strategic landscape of the industries into which they are introduced. And Chapter 1 established that outsourcing decisions are a key element of many companies' overarching strategy. It therefore follows that make-buy decisions are necessarily affected by technological discontinuities. This section therefore reviews the literature that deals with the principal driving motives behind make-buy decisions.

The topic of make-buy decisions is by no means a new one. Nearly 67 years ago, Coase (1937) put forward his theory explaining why companies elect to make some of their inputs in-house and buy the rest from outside firms. A large number of make-buy frameworks have been developed since that time which approach the issue of outsourcing in a slightly different way and with a particular industry or circumstance in mind. And Balakrishnan & Wernerfelt (1986) offer a "vertical integration index" that managers can use to measure quantitatively the degree of vertical integration within a firm. Despite these efforts to rationalize how these decisions ought to happen, however, outsourcing policies very often evolve within organizations via a fairly flexible, tacit decision-making process rather than any kind of explicit methodology (Baines, Whitney, & Fine, 1999; Mills, Neely, Platts, Gregory, & Richards, 1994; Venkatesan, 1992). Alexander &

Young (1996) suggest that as few as one third of companies in the UK have any kind of explicit outsourcing strategy in place.

One compelling reason for this tendency towards relatively soft and informal outsourcing strategies is that the make-buy question rarely boils down to any kind of simple, one-dimensional analysis (Probert, 1996). Walker & Weber (1987) agree that outsourcing judgments are driven by multiple variables, but add that these decisions are not made according to the independent behaviour of these variables; rather, they are sometimes the product of interactions of those factors. The situation is further complicated by the fact that outsourcing decisions are not confined exclusively to either make or buy. A procurement manager can choose from a spectrum of possibilities ranging from full ownership to short-term contracts (Cáñez & Probert, 1999; Probert, Jones, & Gregory, 1993; Quinn & Hilmer, 1994).

In light of the inherent complexity of many make-buy scenarios, making almost any kind of outsourcing decision usually involves a broad range of criteria and concerns, including: cost, available resources, core competencies, product architecture, and strategic considerations. The literature within each of these spheres of research will be explored in turn.

2.2.1 Transaction Cost Theory

Coase (1937) notices a clear division in the way the market links various functions and processes. Some transactions are decided by the mechanisms of the marketplace; others are consolidated into companies, which are essentially organizations in which several functions or activities are combined and orchestrated. Towards explaining this discrepancy, Coase suggests that there are costs to be incurred in any market transaction beyond the direct price of the thing being traded in and of itself. There are, he says, hidden expenses associated with using the market's price mechanism.

The simple act of discovering what the relevant prices are behind a transaction requires some amount of effort, and because labour itself is an input, there is a cost associated with this gathering of information. Moreover, the costs of negotiating and concluding a separate contract for each transaction that takes place in a market must also be taken into account. The formation of an organization—like a company, for instance—in which transactions among parties occur outside of the open marketplace therefore seems like a clever way to reduce or avoid altogether the marketing costs associated with transactions that occur within the market.

However, Coase admits that there are limitations to this logic. If one can eliminate certain expenses and reduce the overall cost of production by organizing several activities into a firm, one might wonder why there are any market transactions at all. All production and every process, this theory would suggest, should be carried out by one big firm. But Coase explains that there are also expenses associated with monitoring what goes on within a company, and the costs of organizing additional transactions within a firm may rise as the firm gets larger. In other words, the larger a company is, the more difficult it becomes to organize all the information pertaining to its internal transactions.

Williamson (1981) builds on this idea by formally rationalizing something that most people take for granted: human nature tends towards opportunism, and people frequently cheat, lie, and mislead one another to fulfil their own interests. This opportunism, Williamson contends, represents a significant "cost" in any business deal with an outside company or individual. Simply put, there is an expense associated with the uncertainty inherent in inter-firm transactions. Williamson adds these unseen expenses to Coase's original transaction costs to explain more completely how a firm comes to obtain supplies and services internally or externally to itself. The economic rents that can be extracted via information asymmetry between parties is also an idea that has been explored in the literature on principal-agent theory (Pindyck & Rubinfeld, 1995). This theme of opportunism is indeed supported by empirical data. Evidence collected from a US automotive firm demonstrates that "the absence of alternative vendors forces the buyer to increase the effort it expends in contract specification and monitoring" (Walker & Weber, 1987, p. 590).

Towards constructing a framework with which managers can rationally sort through the transaction cost aspects of make-buy decisions, Williamson identifies and categorizes transactions along two dimensions, frequency and asset specificity:

> Frequency refers to how often a transaction occurs, either occasionally or recurrently… For example, the purchase of capital investments, such as machinery and buildings, is described as occurring only occasionally. The purchase of materials or supplies is characterized as recurring frequently.
>
> Asset specificity refers to the degree of customization of the transaction. A transaction is highly asset specific if it cannot readily be used by other companies because of site

> specificity, physical asset specificity, or human asset specificity (quoted in Lacity & Hirschheim, 1993, p. 28).

Whether the transaction occurs frequently or occasionally, Williamson (1981) recommends that any kind of transaction involving non-specific investments should be outsourced. Non-specific functions can typically be carried out equally well by any one of several firms in the marketplace, and firms that specialize in these kinds of activities can usually do so for a lower cost than a vertically integrated production team can.

Williamson's concept of "human asset specificity" and the transaction costs associated with it have been explored from at least two other perspectives. Analyzing data from the US auto industry, Monteverde & Teece (1982) suggest that, as transaction cost theory would suggest, car manufacturers are more likely to retain in-house those parts and processes that require a high amount of specialized, non-patentable know-how (p. 206). Lee (2000) uses game theory to explore this same theme, and demonstrates that buyer firms can get burdened with asset-specific transaction costs even if they do not have to invest a lot of money in capital assets that might be specific to a particular job. These costs can also arise because of asset-specific learning.

The complexity of a product or project may also have considerable bearing on its transaction costs. Novak & Eppinger (2001) suggest "that a firm seeking to minimize the coordination costs associated with developing a complex system will internalize production" (p. 190) so that it can minimize the amount of uncertainty. Other evidence, however, suggests that internalizing production does not actually achieve this objective at all. In-house design teams can sometimes be harder to coordinate activities with than external vendors (Venkatesan, 1992).

The transaction cost theory is not without detractors, however. Walker & Weber (1984) offer evidence which suggests that the effect of transaction costs on make-buy decisions is substantially overshadowed by production costs in some industries. Yoon & Naadimuthu (1994) underline the high degree of uncertainty that necessarily impedes any attempt to calculate a firm's transaction costs. And Barney (1999) points out that transaction cost economics tends not to pay a due amount of attention to the capabilities of a company's *potential* partners when deciding which economic exchanges to include within a firm's boundary and which to outsource. To make his point, he offers examples in which there are high degrees of asset specificity and a tremendous amount of potential for opportunism, but in which the price of bringing a new technology in-house is simply too high. In such cases, the transaction cost approach may be considered somewhat shortsighted when a firm is particularly eager to get its hands on desperately needed new capabilities.

2.2.2 Resource-Based Theory

Penrose (1980) suggests that there is a logical limit to how big a firm can get and how many things an individual manager can concern himself with. This perspective is rooted in the understanding that a single manager—or cohesive, functioning management team—can only attend to so many details and issues at any one moment in time, and that a team necessarily only has a finite number of competencies at its disposal. "Behind this notion," Penrose explains, "lay the common-sense deduction that consistency of behaviour requires 'single-minded' direction which is clearly limited in its possible scope simply because the capacity of any human being is finite" (p. 18). Thus, a firm sometimes has to buy components and services from outside companies simply because it is resource-constrained.

2.2.3 Core Competencies

Another principal school of thought in make-buy research believes that firms ought to define for themselves a set of core competencies—that is, a group of capabilities at which the company can be regarded as the industry leader, and on which it focuses its efforts and resources (Porter, 1991; Venkatesan, 1992). Prahalad & Hamel (1990) say that a core competence should be a singular, clearly defined focus that is communicated to everyone within the organization and to the outside world (p. 80). They stress, too, that competencies should not be established around short-term concerns; rather, they can take as long as decades to develop and enhance (p. 85). And instead of narrowly focusing firm's competencies on particular products, Utterback & Meyer (1993) recommend that a company collectively considers its activities by identifying common threads of technological know-how and managerial understanding among them.

Quinn & Hilmer (1994) offer a framework that succinctly captures many of the "key ingredients" of a core competence (pp. 45-47). Specifically, they say that core competencies:

- have to be skill or knowledge sets, not just products or functions
- must be flexible, long-term platforms that are capable of adaptation or evolution
- must be limited in number, i.e. the company cannot have too many competencies to focus on

- must offer unique sources of leverage in the value chain
- must be areas in which the company can dominate
- must exhibit elements that are important to customers in the long run; and
- must be embedded in the organization's systems.

Leonard-Barton (1995) emphasizes that a competence should be highly unique, saying that "such capabilities are core only if they embody proprietary knowledge (unavailable from public sources) and are superior to those of competitors" (p. 4). Bessant & Tsekouras (2001) add that a core competence is something "which differentiates the firm from others and offers the potential for competitive advantage. Acquiring this is not simply a matter of purchasing or trading knowledge assets but the systematic and purposive learning and construction of a knowledge base" (p. 84).

Other research suggests that the macroeconomic context of a firm should also be considered when defining its core competencies. There is evidence that larger market environments—e.g. the US as opposed to South Africa—tend to be more appropriately geared to the production of a relatively narrow range of products, and are less supportive of firms with competencies that are applicable across a wide range of products (Arora & Gambardella, 1997). Simply put, this research suggests that the breadth of the competencies possessed by the firms within a particular country will become more focused and narrow as the firms' market size increases (p. 72).

Fine & Whitney (1996) believe that core competencies are more fundamental than what is described above, saying that "the main skills companies should retain transcend those directly involving product or process, and are in fact the skills that support the very process of choosing which skills to retain" (p. 2). Alexander & Young (1996) agree, adding that the art of making prudent outsourcing decisions may in itself be a source of competitive advantage. "There is no reason," they say, "why organizations cannot develop competitive advantage in the activity of specifying and integrating external services and other purchases, rather than in generating the services or making the goods themselves" (p. 118). Nike is a particularly compelling example of this type of business model. The company is the largest supplier of athletic shoes in the world, yet outsources 100 percent of its shoe production and manufactures only key technical components of its "Nike Air" system (Quinn & Hilmer, 1994, p. 43).

The core competencies approach to resolving make-buy questions is not without limitations, though. First, as Venkatesan (1992) points out, despite a company's steadfast commitment to stick to its chosen competencies, naturally occurring forces often motivate managers to violate these principles. At best, a manager might elect to retain a particular component or process in-house because such a move would preserve jobs; at worst, they would keep it in-house because "more parts means more responsibility, more authority, and bigger salaries" (Venkatesan, 1992, p. 100) for the managers themselves.

Second, despite executives' efforts to the contrary, different managers throughout a company typically have significantly different ways of thinking about what is "core" (Alexander & Young, 1996, p. 117). And while Prahalad & Hamel (1990) suggest that companies should retain in-house those skills and learning opportunities that they will need for the next generation of their products, Alexander & Young (1996) underline that it is often hard or even impossible to identify in advance where this "new learning" will come from. Christensen & Raynor (2003) also discuss the transient nature of core competencies, noting that "what might seem to be a non-core activity today might become an absolutely critical competence to have mastered in a proprietary way in the future, and vice versa" (p. 125).

2.2.4 Product Architecture

Another issue playing a significant role in outsourcing judgments is the architecture of the product. A product's architecture "determines its constituent components and subsystems and defines how they must interact—fit and work together—in order to achieve the targeted functionality" (Christensen & Raynor, 2003, p. 127). While the literature offers evidence that a product's architecture can play a non-trivial role in make-buy decisions (Probert, 1996; Veloso & Fixson, 2001), Fine & Whitney (1996) consider it to be a key criterion. Citing earlier work by Ulrich (1995), Fine & Whitney draw a clear distinction between products that have *modular* architecture and those that have an *integral* architecture:[4]

> A product with a modular architecture has components that can be "mixed and matched" due to standardization of function to *some* degree and standardization of interfaces to an *extreme* degree. Home stereo equipment has a modular architecture; one can choose speakers from one company, a CD player from another, a tape deck from a third, etc., and all the parts from the different manufacturers will assemble together into a system. IBM-compatible computers are also quite modular with respect to [their] CPU, keyboard, monitor, printer, software, etc., as are adults' bicycles.
>
> A product with an integral architecture, on the other hand, is not made up of off-the-shelf parts, but rather comprises a set of components and subsystems designed to fit with each other. Functions typically are shared by components, and components often display

[4] Christensen (2002) discusses this same concept, but refers to it as "interdependent architecture."

> multiple functions… the product must be developed as a system and the components and subsystems defined by a design process exerted from the top down, rather than the bottom-up design process that may be used by a bicycle manufacturer (p. 10).

Fine & Whitney also separate the ways in which a company can be dependent on its suppliers: by relying on them for production capacity, or by depending on them for knowledge. By concurrently analyzing the decomposability of a product and the nature of the outsourcing firm's dependence on its suppliers, Fine & Whitney offer a framework for outsourcing, shown in Figure 2.3, which highlights potential strategic traps and opportunities.

Using historical evidence from several industries and building on his earlier observations about the role of product architecture in make-buy decisions, Fine (1998) also points out that industries' outsourcing practices generally evolve according to a "double helix" pattern:

> 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; and
> 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...
>
> On the other hand, when an industry has a horizontal 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 (pp. 48-50).

2.2.5 Strategic Approaches

Many companies' knee-jerk reaction when arriving at a make-buy decision is to focus almost exclusively on the financial and cost-related aspects of the problem (Probert *et al.*, 1993; Quinn & Hilmer, 1994; Welch & Nayak, 1992). "It is this apparent calculability of the financial aspects, with the often associated assumption of precision, that leads to a bias towards these considerations in process guidance to date" (Probert *et al*., 1993, p. 242). The weakness of this approach, however, is that it tends to overlook the strategic implications of judgments that necessarily have tremendous bearing on the overall strategic direction of the company. Quinn & Hilmer (1994) highlight the fact that it is important not to outsource every non-core activity with a total disregard for all the other considerations (p. 44). They point out that, to preserve its core competence, a company must take steps to prevent other firms from compromising its preeminence in that field:

> It may also need to surround these core competencies with defensive positions, both upstream and downstream. In some cases, it may have to perform some activities where it is not best-in-world, just to keep existing or potential competitors from learning, taking over, eroding, or bypassing elements of its special competencies. In fact, managers should consciously develop their core competencies to strategically block competitors and avoid outsourcing these or giving suppliers access to the knowledge bases or skills critical to their core competencies (p. 47).

Monteverde & Teece (1982) agree with this idea, and accordingly caution managers that suppliers can become very opportunistic by noting that "overly powerful suppliers can hold the company ransom" (p. 49).

Looking at the long-term consequences of outsourcing, Quinn & Hilmer (1994) and Fine & Whitney (1996) point to an important strategic consideration that is often overlooked: learning and the knowledge residing within the firm. They suggest that many Western firms seem to lose control of their core competencies in the name of short-term cost savings. Japanese managers, by contrast, outsource in a way that increases their own knowledge, and build close interdependent relationships with their suppliers.

2.2.6 Technology's Impact on Outsourcing

With the advent of e-mail, facsimile machines, and the internet, people in different firms from all over the world can now transfer information back and forth more cheaply and easily than ever before. Accordingly, many of the transaction costs associated with doing business with outside firms are falling dramatically. These changes are having a profound effect on make-buy decisions. Alexander & Young (1996) note a sharp increase in the amount of outsourcing in many industries, and predict more of the same in the future. Grossman & Helpman (2001) indicate that "improvements in transportation and communication technology have lowered the cost of search for outsourcing partners. The internet, especially, has facilitated business-to-

	Dependent for Knowledge and Capacity	Dependent for Capacity Only
Item is Modular (Decomposable)	**A Potential Outsourcing Trap** Your partners could supplant you. They have as much or more knowledge and can obtain the same elements as you can.	**Best Outsourcing Opportunity** You understand it, you can plug it into your process or product, and it probably can be obtained from several sources. It probably does not represent competitive advantage in and of itself. Buying it means you save attention to put into areas where you have competitive advantage, such as integrating other things
Item is Integral (Not Decomposable)	**Worse Outsourcing Situation** You don't understand what you are buying or how to integrate it. The result could be failure since you will spend so much time on rework and rethinking.	**Can Live With Outsourcing** You know how to integrate the item so you may retain competitive advantage even if others have access to the same item.

Figure 2.3: Matrix of Organizational Dependency and Product Decomposability [Fine (1998, p. 169)]

business matching. Also, changes in production methods associated with computer-aided design may have reduced the cost of customizing components" (p. 27).

These changes in the marketplace are also causing inter-firm relationships to become much more fluid and temporary than they used to be. "When everyone can communicate richly with everyone else, the narrow, hardwired communications channels that used to tie people together simply become obsolete. And so do all the business structures that created those channels or exploit them for competitive advantage" (Evans & Wurster, 2000, p. 13). The US auto industry is just one example of how this new way of thinking is reshaping traditional roles. GM has joined forces with Ford and DaimlerChrysler to create an independent, internet-based auction system that will allow the sponsoring companies to buy parts and components from whatever supplier offers the best terms.[5]

The scope of what suppliers are capable of doing is also markedly different from what it once was. Quinn & Hilmer (1994) suggest that, because "of greater complexity, higher specialization, and new technological capabilities, outside suppliers can now perform many… activities at lower cost and with higher value added than a fully integrated company can" (p. 51). And while previous generations of suppliers were often small players that manufactured individual parts, today's suppliers are very proficient with CAD/CAM,[6] are highly precise, and spend considerable amounts of money on R&D (Kumpe & Bolwijn, 1988; Veloso & Fixson, 2001).

The first section of this chapter discussed what radical innovations are and the ways in which they bring about profound changes in firms—and, indeed, entire industries. The second section explored the various factors that influence make-buy decisions in general and underlined that, like radical innovations, outsourcing judgments are an important consideration in any company's overarching strategy. The next section of this chapter will review literature that effectively draws the previous two sections together by looking at how make-buy strategies are shaped by the emergence of radical innovations.

2.3 How Radical Innovations Shape Make-Buy Strategies

2.3.1 The Emergence of Suppliers as Innovators

Product and process lifecycles are steadily growing shorter, thereby forcing firms to develop almost continuous streams of innovation (Fine, 1998; Loudon, 2001; Piachaud, 2000). But at the same time, it is becoming increasingly difficult for any one company to support an aggressive R&D agenda single-handedly. Many firms have accordingly turned to their supply networks as a source of innovation. And to be sure, there is evidence that it is quite healthy for companies to rely to some degree on their supply network for new ideas. Based on observations from the auto

[5] This change of tack is all the more dramatic when you consider that GM owns a partial stake in many large parts vendors such as Delphi.

[6] These abbreviations stand for "computer aided design" and "computer aided manufacturing," respectively.

industry, Quinn (2000) notes that "there is a high correlation throughout the industry between a company's degree of outsourcing, its innovativeness and its product margins and ROI[7]" (p. 16).

There are two principal reasons for this growing tendency for companies to outsource innovation. First, the costs associated with modern-day R&D projects are an increasingly daunting proposition (Cáñez & Probert, 1999; Kumpe & Bolwijn, 1988; Manders & Brenner, 1995). Robert Z. Gussin, the former Vice President for Science and Technology at Johnson & Johnson, once drove this point home by musing that technology "has become so sophisticated, broad, and expensive that even the largest companies can't afford to do it all themselves" (Leonard-Barton, 1995, p. 135). And the crippling costs of research have influenced companies' ability to innovate in some other, less obvious ways. Firms that are working hard to remain technologically active can inadvertently lock themselves into an outdated technology by investing too much in it all by themselves, thereby creating high exit barriers (Harrigan, 1984). For example, the US auto industry was slow to make the transition to disc brakes because of its huge investment in cast iron brake drums (Hayes & Abernathy, 1980).

Also focusing on the economic costs and benefits of the innovation process, von Hippel (1988) proposes that "analysis of the temporary profits ('economic rents') expected by potential innovators can by itself allow us to predict the functional source of innovation" (p. 5). Thus, according to this theory, the decision to involve a supplier in the innovation process or to pursue these types of activities entirely in-house is heavily influenced by the economic incentive offered to firms situated at different points in the value chain. Referring to data from several industries, von Hippel (1998) suggests that "innovating firms could reasonably anticipate higher profits than non-innovating firms" (p. 5).

The second motive for outsourcing innovation is that history has shown on many occasions that even the most focused R&D programs fail to consistently guarantee results (Holton, Chang, & Jurkowitz, 1996). Many of the significant and commercially celebrated innovations that have emerged over the years have not been the result of tightly managed research agendas, but were instead brought about by a convoluted process of serendipity and unique circumstances (Afuah, 1998). Holton, Chang, & Jurkowitz (1996) highlight the hit-and-miss nature of R&D by saying that "[e]ven in the best of times, managing science has been compared to herding cats; it is not done well, but one is surprised to find it done at all" (p. 364).

[7] ROI is an abbreviation for "return on investment," a measure of how well a business is performing.

Realizing that it is almost impossible to forecast where their next "new big thing" will come from, many companies are starting to broaden the radius of ideas that they might tap into by turning to their supplier base (Chesbrough, 2003; Rigby & Zook, 2002). Quinn & Hilmer (1994) point out that Apple "benefited from its vendors' R&D and technical expertise, kept itself flexible to adopt new technologies as they became available, and leveraged its limited capital resources to a huge extent" (p. 44). This trend is spreading to many firms throughout many areas in the marketplace: "in a number of industries studied, two-thirds of all innovation occurred at the customer-supplier interface" (Quinn & Hilmer, 1994, p. 53). Quinn (2000) demonstrates, too, that this strategy need not apply exclusively to supplier companies. He points out that large pharmaceutical firms have been using universities and government laboratories to help develop the basic research underpinning new product streams.

But Nicholls-Nixon & Woo (2003) recommend that firms retain some innovation functions in-house while using suppliers as a source of new ideas. Based on data from the US pharmaceutical industry, they "argue the need for 'dual sourcing'… whereby firms utilize both internal and external R&D as a means of developing new technical outputs" (p. 651). They reason that "together, internal and external R&D build the 'absorptive capacity' that underlies current and future technical output" (p. 652).

2.3.2 The Role of Product Architecture

Suppliers may be able to broaden the resource base and generate good ideas that a customer firm can benefit from, but the architectural nature of the new products themselves sometimes makes it somewhat cumbersome to do so successfully. Citing Christensen's data from the hard disk drive industry over several product generations, Fine & Whitney (1996) observe that "generational breakthroughs typically require an integrated product architecture created by a vertically integrated firm, with correspondingly limited outsourcing" (p. 26).

Christensen (2002) offers an explanation as to why this is the case. He reasons that successful innovators in the marketplace tend to be those whose products are based on a relatively integrated architecture. This happens, he says, because "competitive pressure compels engineers to fit the pieces of their systems together in ever more efficient ways in order to wring the best performance possible out of the available technology" (p. 36). By contrast, having standardized interfaces—what Fine & Whitney (1996) refer to as having a "modular" architecture—inhibits the degrees of freedom for engineers working on the new product, and forces "them to back away from the frontier of what is technologically possible" (Christensen, 2002, p. 36). More degrees of freedom pave the way for unstructured technical dialogue among engineers, which is in turn "the language required to compete successfully when a product's functionality is not good enough to address targeted customers' needs" (Christensen, Verlinden, & Westerman, 2001, p. 6).

But this strategy may not continue to be the best one as the technology matures. As shown in Figure 2.4, when "the functionality of products has overshot what mainstream customers can use… companies must compete through improvements in speed to market, simplicity and convenience, and the ability to customize products to the needs of customers in ever smaller market niches. Here, competitive forces drive the design of modular products, in which the interfaces among components and subsystems are clearly specified" (Christensen, 2002, p. 36). Fine & Whitney (1996) make a similar observation, noting that this process of modularization

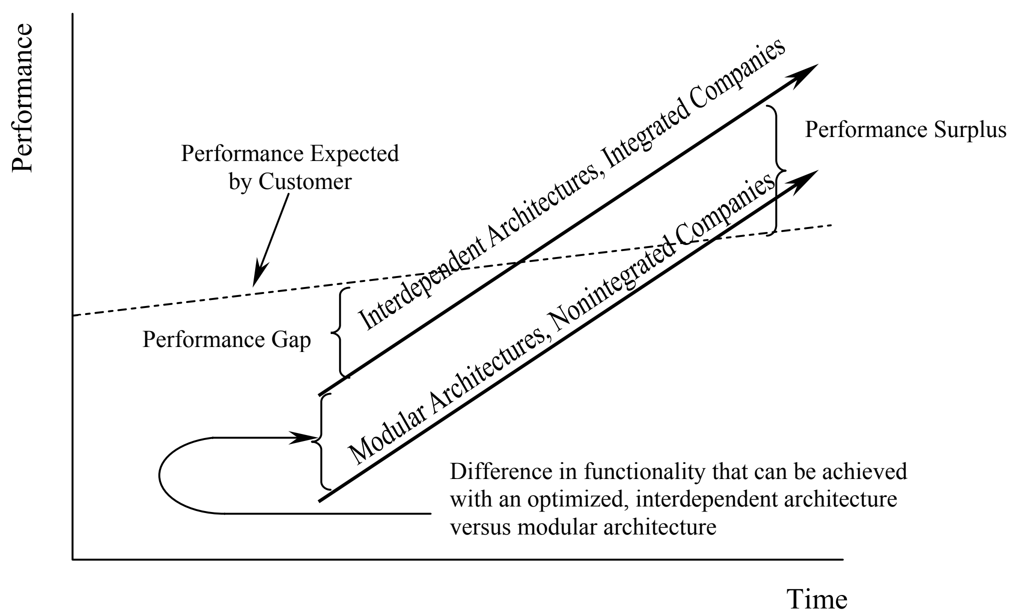

Figure 2.4: Product Architectures and Integration
[Christensen & Raynor (2003, p. 127)]

seems to occur naturally in the marketplace: "Within generations, components get defined and commoditized, the industry becomes more horizontal, suppliers are numerous, and outsourcing is easier" (p. 36).

2.3.3 Asset Specificity

Other evidence suggests that the amount and kind of outsourcing that occurs in an industry is significantly shaped by the degree of specialization of assets underpinning the technology. Building on prior work in the area of asset specificity (e.g. Monteverde & Teece, 1982; Walker & Weber, 1984), Balakrishnan & Wernerfelt (1986) argue that "while uncertainty in general will make the integration more effective, a particular type of uncertainty, the possibility of technological obsolescence, works the other way" (p. 347). They also note that these kinds of assets:

> have a very low value in their secondary use, making their value drop noticeably if technical change should render them obsolete in their primary use. The expected long-run profitability of a specialized asset is therefore much lower in the presence of frequent technical change. Putting these two arguments together we would expect vertical integration to be less desirable in industries with more participants (less specialized assets, lower profits) and more frequent technical change… as the likelihood of obsolescence goes up, the expected profitability of the investment goes down, and with it the incentive to bargain and hence the gains from vertical integration (p. 348).

2.3.4 Cultural and Environmental Motives

Some arguments in the literature focus on characteristics of the companies themselves and the people who work for them. Barney (1999) and Leifer *et al*. (2000) both underline how important it is to preserve the corporate culture and environment that brings an innovation into being. In those situations where a new and breakthrough idea was brought about by suppliers, strategic alliances between the supplier and customer firms seem to be preferable to outright acquisitions. "Research indicates that most acquisitions fail. By far the most important reason for this failure is the inability of acquiring firms to take full advantage of newly acquired capabilities. Integration difficulties stem from differences of culture, systems, approach, and so forth. Such differences raise the cost of using acquisitions to gain access to capabilities" (Barney, 1999, p. 143). Afuah (1998) makes a similar observation about technology transfers between companies, noting that "[d]ifferences in culture between transmitting and receiving firms can make the transfer of innovation very difficult" (p. 77).

Another organizational aspect of make-buy judgments is the customer firm's future ability to learn. A company may benefit handsomely by outsourcing the innovation process for the next generation of technology—but will this good fortune continue in subsequent generations? In the blind pursuit of short-sighted gains, "companies may be ceding the very skills and processes that have distinguished them in the marketplace" (Doig, Ritter, Speckhals, & Woolson, 2001, p. 26). Hayes & Abernathy (1980) echo this idea by pointing out that in "deciding to integrate backward because of apparent short-term rewards, managers often restrict the ability to strike out in innovative directions in the future" (p. 72).

Harrigan (1984) offers evidence from the microprocessors and memory chip industries which shows that companies sometimes do indeed place a premium on the learning to be gained by doing something in-house. She notes that some manufacturers in these sectors make inputs themselves even when they cost more in-house so that the company can "carry over knowledge to the next generation of active components for which they might seize preemptive or cost advantages" (p. 650). Bessant *et al*. (2003) point out, however, that the benefits of learning should not merely be considered at the firm level, but with the whole value network in mind. They suggest that "competitive performance of the value stream depends upon learning and the development of the whole system, not just the leading players" (p. 167).

Afuah (2001) suggests that the channels of communication within an organization are a key ingredient in an innovation's success, and contends that a "make" decision is usually more prudent than "buy" in the early days of a new technology. He points out that when a group of people are trying to develop a new technology, knowledge "is often tacit—that is, uncoded, nonverbalized, and often embedded in organizational routines and in individuals' actions" (p. 1212). People can therefore work better and develop ideas faster within a single organization than among different ones. "Product development requires frequent, often in-person interaction between the different units with the knowledge that underpins each of the components of a system" (p. 1216). Allen & Cohen (1969) arrive at a similar conclusion, noting that research and development frequently result "from the interaction of both social relations and work structure" (p. 12). They suggest that research colleagues who engage in regular face to face communication with one another are typically more productive than those who do not have a high degree of direct interaction.

The issue of make-buy decisions for new technologies has also been approached from a conflict resolution point of view. The act of developing new products and processes necessarily requires the making of many decisions and trade-offs by groups of people. Chesbrough & Teece (1996) suggest that this is an important reason why vertical integration is usually a good idea in new technology environments. So-called "virtual organizations" and the idea of outsourcing innovation are an attractive concept because "we have come to believe that bureaucracy is bad and flexibility is good" (p. 65). They explain, however, that "integrated, centralized companies do not generally reward people for taking risks, but they do have established processes for settling conflicts and coordinating all the activities necessary for innovation" (p. 66). Conceding that there are pluses and minuses to either approach—that is, vertical integration vs. virtual organizations—the authors suggest that perhaps an in-between solution is appropriate. "If virtual organizations and integrated companies are at opposite ends of the spectrum, alliances occupy a kind of organizational middle ground" (Chesbrough & Teece, 1996, p. 67).

2.3.5 Robustness of "Co-Opetitors"

Most of the literature discussed in this section has looked at firms' make-buy strategies by scrutinizing almost exclusively how well the customer firm succeeds with a particular strategy. But what about the firm's "co-opetitors"—that is, its suppliers, customers, and complementors?[8] What happens to *their* respective competitive advantages? It is fairly obvious that firms often lose competitive advantage when a disruptive technology renders their own capabilities obsolete. But the survival or failure of a firm's co-opetitors is also critically important insofar as the firm's future success may hinge on the wellbeing of these other groups (Abernathy & Clark, 1985; Afuah, 2000). "A firm's strategies," say Hill & Rothaermel (2003), "are constrained by external forces that provide critical resources to the firm, such as customers, suppliers, and investors" (p. 261).

Looking at 23 computer workstation firms that adopted reduced instruction set computer (RISC) technology, Afuah (2000) argues that sometimes "a firm's post-technological change renders co-opetitors' capabilities obsolete" (p. 387). A company, he suggests, is necessarily linked to other organizations, and should not be regarded as a standalone entity. Via a statistical analysis of firms' performance after the shift to the RISC-based technology in the computer industry, Afuah

[8] Afuah (2000) credits Nadar, a former CEO of Novell, with coining the term "co-opetitor." But the word "complementor," a word that describes firms which make products that are complementary to those of another product, seems to be of his own making.

concludes that "the more a technological change renders obsolete the capabilities of a firm's suppliers or customers,[9] the poorer the firm performs" (p. 399). He suggests that this can be a very difficult problem to spot when leaping from one technological generation to the next, however. This difficulty often arises because "a firm's ties with suppliers that may be a source of advantage in exploiting an existing technology, can become a handicap in the face of a technological change that renders suppliers' capabilities obsolete" (p. 399). Thus, a company's links to existing suppliers may not only be useless when an innovation is ushered into the marketplace, but may in fact be a handicap inasmuch as firms are often hesitant to cut ties with existing suppliers in favour of new ones.

Focusing on new product development (NPD) projects undertaken by multiple firms, Primo & Amundsen (2002) show that "critical suppliers can hurt project progress. It looks like suppliers per se do not tend to speed an NPD project, but they tend to slow it down (especially critical suppliers) by uncooperative attitudes or low priority given to a specific buyer" (p. 50). Utterback (1994) also observes that links with suppliers can sometimes hobble an incumbent firm:

> One reason for the lethargy of well-established competitors in a product market in the face of potentially disruptive innovation is that they face increasing constraints from the growing web of relationships binding product and process change together… Thus change in one element, the product, requires changes throughout the whole system of materials, equipment, methods, and suppliers. This may make changing more onerous and costly for the established firm than for the new entrant (p. xxvii of introduction).

Focusing on 336 companies that made the technological leap from the complex instruction set computer (CISC) instruction set architecture standard to the faster RISC standard, Afuah (2001) goes some way towards reconciling differing conclusions from various points of view and disciplines. Some studies have argued that in industries with high rates of technological change, firms are better off not being vertically integrated; other researchers disagree, claiming that the more uncertainty a firm faces, the more likely it is to vertically integrate. Afuah argues that these conclusions are in reality two sides of the same coin. He explains that, "following a technological change that is competence-destroying to firms and their suppliers, firms that are integrated vertically into the new technology will perform better than those that are not. At the same time, firms that had been vertically integrated into the old technology will perform worse than those

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[9] How these changes might affect customers is sometimes less than obvious. Afuah (2000) offers as an example the case of the QWERTY keyboard. The proposed change in the typewriter industry to the Dvorak keyboard did not represent a problem for the typewriter companies or their suppliers, but it wrought havoc among the end users. Such a move was essentially competence destroying to the customers inasmuch as none of them knew how to type with the new keyboard configuration.

that had not been" (Afuah, 2001, p. 1211). His essential message is that the efficient boundaries of a firm are dynamic: vertical integration is good at some points, but not at others. The make-buy strategy has to change as the technology matures.

2.4 Identifying the Gap

One of the striking things about the literature in the field of make-buy decisions for radical innovations is that it seems not to agree on any one strategy or prescription. Some authors offer a compelling case for retaining new technologies in-house; others advocate outsourcing them to a supplier. A few even suggest using both strategies, but at different times. This lack of agreement points to the fact that the scheme of classification used to analyze make-buy decisions in the face of radical innovations is unfinished.

Christensen & Sundahl (2001) explain the process by which theories are built, and highlight several potential ways in which research can contribute to this: "The process of theory-building, which is iterative, can be divided into several stages. In the earliest stages of theory-building, the best that researchers can do is to observe phenomena, and to carefully describe and record what they see" (p. 1). Once the phenomenon has been observed and described, researchers can then classify the phenomena into categories of similar things. Theories can then be built that explain the behaviour of the phenomena. But as shown in Figure 2.5, this process does not progress in only one direction; rather, it continues in a loop to "approach a perfect understanding of what causes what, and why, under what circumstances" (Christensen & Sundahl, 2001, p. 3).

Christensen & Sundahl (2001) also make a distinction between pre-paradigmatic and post-paradigmatic cycles of theory building. In pre-paradigmatic cycles, researchers focus on finding anomalies and on developing conceptual definitions of categories. Post-paradigmatic cycles, by contrast, involve figuring out "how to measure the phenomena for classification and prediction purposes; developing instruments to do that work; and so on—because the classification schemes have been broadly accepted" (p. 4). Systems of classification, they say, should ultimately be collectively exhaustive and mutually exclusive.

Therein lies the contribution of this investigation. The lack of convergence in the literature suggests that the scheme of categorization used to analyze make-buy decisions in the face of radical innovations is not yet complete. As Christensen & Sundahl (2001) suggest, an incomplete

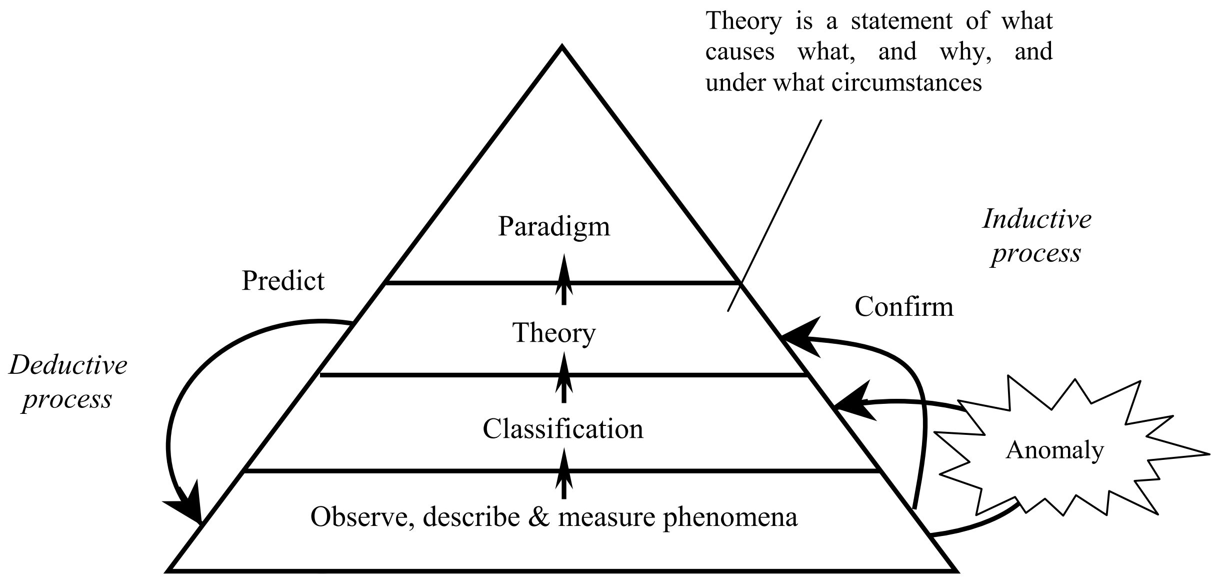

Figure 2.5: The Process by Which Theory is Built
[Christensen & Sundahl (2001, p. 3)]

categorization system does not in any way discredit prior work; it merely suggests that "[t]here must be something else going on here" (p. 10). It is possible that at least part of this "something" can be found within literature from the fields of (1) supplier relationships and (2) industry clockspeed. This research will attempt to determine if and how these factors should be added to the existing system of categorization applied to make-buy decisions for radical innovations.

2.5 The Importance of Long-Term Cooperative Relationships with Suppliers

Managers who arrive at make-buy decisions are often driven by forces other than technology and the vagaries of the market. Foster (2000) argues that "human beings… engage in economic behaviour both because of 'rational' economic thinking, as it is conventionally understood, and because of emotional arousal" (p. 374). And Teece (1992) acknowledges that competition is essential to the innovation process, "but so is cooperation" (p. 1). Accordingly, this section will explore prior research in the area of trust and supplier relationships, and will discuss the benefits that manufacturers can achieve by developing long-term relationships with their suppliers.

2.5.1 Types of Trust and Inter-Firm Relationships

Broadly defined, trust is "an expectation held by one trading partner about another, that the other behaves or responds in a predictable and mutually acceptable manner" (Sako, 1992, p. 37). It is also "an intangible capital asset owned jointly by two parties to a relationship. What is peculiar about trust… is that it may only be acquired slowly but can generally be destroyed very quickly" (Sako, 1992, p. 41). Kumar (1996) adds that "what really distinguishes trusting from distrusting relationships is the ability of the parties to make a *leap of faith*: they believe that each is interested in the other's welfare and that neither will act without first considering the action's impact on the other" (p. 95).

The literature identifies several different kinds of trust. Relationships based on trust may exist at both the personal and organizational levels (Galford & Drapeau, 2003; Tidd, Bessant, & Pavitt, 2001; Zaheer, McEvily, & Perrone, 1998). Tidd *et al*. (2001) explicitly point to six varieties of trust—contractual, goodwill, institutional, network, competence, and commitment—that are similar in many respects to the categories established by Sako (1992): contractual trust, competence trust, and goodwill trust.

Contractual trust is "predicated on both trading partners upholding a universalistic ethical standard, namely that of keeping promises" (Sako, 1992, p. 37). The kinds of promises to be kept within this kind of trust may not always be consistent with bilaterally agreed rules, but will tend to adhere to rules that are more generally applicable to business as a whole. This type of relationship is guided more by oral agreements than by written ones. Contractual trust "rests on the moral norm of honesty and keeping promises which is inculcated in people through socialization and education" (Sako, 1992, p. 43).

Competence trust, by comparison, "concerns the expectations of a trading partner performing its role competently" (Sako, 1992, p. 37). It is a necessary condition for the viability of any kind of repeated transactions, and "may be attained either by 'purchasing' existing competences in the marketplace or investing in creating competences. The latter may involve the customer company transferring its proprietary technology to its suppliers, or the customer and the supplier working closely to develop jointly new products or processes" (Sako, 1992, p. 43).

Goodwill trust "is of a more diffuse kind and refers to mutual expectations of open commitment to each other" (Sako, 1992, p. 38). There are no explicit promises that are expected to be filled, as in the case of contractual trust, nor fixed professional standards to be attained, as for competence trust. "Instead, someone who is worthy of 'goodwill trust' is dependable and can be endowed with high discretion, as he can be trusted to take initiatives while refraining from unfair advantage taking" (Sako, 1992, p. 39).

2.5.2 Trust as a Tool for Managing "Bounded Rationality"

A recurring problem in the management of innovation is that collaborating firms find it difficult to define rules and contracts to support products and technologies that are still in their nascent stages of development, or that do not exist at all. It is often impossible to foretell exactly how an industry will respond to a new technology, and it is therefore difficult to write contracts and agreements with suppliers that account for every eventuality that might arise in the marketplace. As Williamson (1993) says, "all viable forms of complex contracting are unavoidably incomplete" (p. 92). Known to economists as "bounded rationality," this principle is rooted in the fact that there are limits to human knowledge and the ability of people to calculate exactly what the future will hold.

Towards reducing their risk when working collaboratively with unfamiliar firms, managers dealing with new suppliers often have to expend significant amounts of time, money, and resources to put together meticulous contracts outlining a legal framework for the relationship (Williamson, 1993). But this would be less of a priority in situations where the firms already had a long-term history of working together. As Hardy, Phillips, & Lawrence (1998) suggest, trust "is supposed to make interorganizational relations function more effectively by curtailing opportunistic behaviour, by reducing complexity, and by fostering coordination and cooperation in ways that more formal contracts cannot" (p. 64). Thus, when each of the consenting parties trusts one another, the legal framework between them usually does not have to be so meticulously and explicitly spelled out, and both sides can proceed comfortably even though their agreement remains unavoidably incomplete (Kern & Blois, 2002; Sako, 1992). Tidd *et al*. (2001) essentially agree with this, adding that "mutual knowledge and social bonds develop through repeated dealings, increasing trust and reducing transaction costs" (p. 215). In this way, a company in a more stable trust-based relationship can have the luxury of spending less money to overcome the problems associated with "bounded rationality."

2.5.3 Lean Supplier Relationships

The lean manufacturing system developed in Japan after World War II is fundamentally different in many regards from the mass production system championed by North American and European manufacturers throughout most of the last century. One of the key differences is the lean system's notion of the "extended enterprise"—a group of closely knit firms that draws on the synergy of its members to create a highly productive corporate family. This concept is founded on the understanding that the combined resources, experiences, and ideas of several companies can, if managed correctly, outperform those of any single firm.

Indeed, this cooperative approach is quite different from the "arm's length" way of doing business that has traditionally been practised by many firms in the West (Gietzmann, 1995). Quinn & Himler (1994) note that Japanese managers tend to build close, interdependent relationships with their suppliers. These closer relationships have played a pivotal role in helping companies like Toyota manufacture cars with half the tool investment, half the engineering hours, and half the development time that a more traditional Western manufacturer would require (Womack, Jones, & Roos, 1990).[10]

But by no means have the benefits of lean-style relationships been confined to Asian companies. Eisenhardt & Schoonhoven (1996) look at inter-firm alliances within the US semiconductor industry and discover that "alliances form when firms are in vulnerable strategic positions either because they are competing in emergent or highly competitive industries or because they are attempting pioneering technical strategies" (p. 136). They note, too, that that these alliances tend to be led by well-connected top management teams, thereby underlining the importance of the social aspects of these arrangements. Similarly, Bozdogan *et al*. (1998) suggest that cooperation between suppliers and customer firms in the early phases of project development in the US defence aerospace industry has resulted in "not marginal but significant improvements" (p. 165). Intel's managers regard their long-term commitment to cooperative relationships as a critical part of the company's leadership in the industry (Gawer & Cusumano, 2002; Perrons, 2004). And Chrysler brought about dramatic improvements by transplanting many aspects of lean-style supplier relationships into its own value network (Dyer, 1996).

Porter (1980) also extols the benefits of establishing stable relationships with suppliers. "Both

[10] As Esposito & Raffa (2001) point out, however, some firms that claim to engage in long-term supplier relationships revert back to classical "arm's length" trading terms during industry downturns.

upstream and downstream stages, knowing that their purchasing and selling relationship is stable, may be able to develop more efficient, specialized procedures for dealing with each other that would not be feasible with an independent supplier or customer—where both the buyer and seller in the transaction face the competitive risk of being dropped or squeezed by the other party" (p. 305).

Leifer *et al*. (2000) agree, adding that "all action, including economic action, is embedded in a social fabric of opportunities to interact. Interaction and ultimately cooperation are likely to happen among people who know one another… These personal relationships create opportunities for cooperation by deepening awareness, trust, and commitment among parties within the relationship" (p. 138). They say, too, that "the evolution of awareness, mutual knowledge, and trust… is central to the creation of cooperative relationships" (p. 138). Glasmeier (1997) suggests that "economic, social, and cultural conditions interact to form a complex of human relations that can remain flexible and innovative over time" (p. 25). Other research points to other important factors that contribute to these relationships. Barney (1999) underlines the value of culture and reputation; Quinn (2000) stresses the importance of sharing goals, ethics, and a common sense of purpose.

Tidd *et al*. (2001) suggest that, where the supply market is more differentiated, manufacturers should consider developing more substantial links to suppliers. "In this case some form of 'partnership' or 'lean' relationship is often advocated, based on the quality and development lead-time benefits experienced by Japanese manufacturers of consumer durables, especially cars and electronics" (p. 205).

Many companies are moving towards systems of innovation that involve close-knit relationships with other firms (Sako, 1992), and the technology management literature has also started to appreciate the increasing role of trust and long-term relationships in the development of new technologies (Bartlett & Ghoshal, 2002; Hoecht & Trott, 1999; Minshall, 1999). These research efforts point to specific cases in which companies improved their bottom lines by collaborating with suppliers in R&D projects, resulting in:

> ***Hypothesis 1:*** *Close relationships between customer firms and principal suppliers that are built on trust and personal relationships play an important long-term role in the development of potentially radical innovations.*[11] *Firms that do not engage in these types of relationships will therefore perform worse in the long-term than those that do.*

2.5.4 Suppliers' Ability to Reinvent Themselves

Afuah (2000) points out that a technological discontinuity may render the capability of suppliers obsolete, but there is support for the idea that suppliers can learn new technologies and capabilities in a way that will allow them to continue to meet their customers' needs. Utterback & Meyer (1993) offer evidence which suggests that core capabilities are inherently dynamic, and that skill sets can evolve significantly over time. Collins & Porras (1996) examine 18 companies—among them, GE, IBM, 3M, and Walt Disney—that have led their respective industries over decades, and attempt to uncover common themes and keys to success. The authors offer some important observations. First, each of the successful companies in the study puts a tremendous amount of emphasis on its corporate culture, and regards its people as being the company's most important resource. Relationships and long-term goodwill are therefore internally perceived as being pivotal ingredients to the success of these firms.

Second, the companies tend not to confine their activities to one type of business model or technology. There are several compelling examples of companies that have re-invented themselves over and over again, each time embracing dramatically new technologies and skills. American Express, 3M, and Nokia are three examples of how companies can prosper not by mastering a specific technical skill, but by building dramatically different business models on a foundation of corporate culture and long-term relationships that transcend any particular technology. Collins & Porras (1996) tell the story of American Express:

> American Express began life in 1850 as a regional freight express business (essentially the nineteenth-century equivalent of the United Parcel Service). In 1882, the company took a small, incremental step that turned out to be the genesis of a dramatic shift. Due to the increasingly popular postal money order, American Express faced declining demand for its cash-shipping services (similar to an armoured car service). In response, AmEx created its own money order. The 'Express Money Order' became an unexpected success—11,959 of them sold during the first six weeks. AmEx aggressively seized the opportunity and began

[11] As Teece (1992) points out, the development of new products and processes "often requires horizontal as well as vertical cooperation" (p. 12). But horizontal linkages between rival firms often involve strategic dynamics and antitrust concerns that are quite different from those between vertically linked firms. Thus, in the interest of focusing on vertically linked companies, this investigation does not take into account any kind of horizontal cooperation.

> selling the product not only at its own offices, but also at railroad stations and general store, and thereby began—unwittingly—to transform itself into a financial services company (pp. 142-143).

Similarly, the historical underpinnings of 3M are quite removed from its current focus. The company began as a supplier of mineral deposits for grinding wheel abrasives, but now manufactures a range of goods as diverse as pharmaceuticals, radiology equipment, and office products.[12] Nokia had a similarly unpredictable evolutionary path: starting in 1865 as a manufacturer of paper, the company is currently a world leader in mobile phones and telecommunications networks.[13]

As Collins & Porras (1996) note, many companies that have been leaders over the long-term tend to put a tremendous amount of emphasis on their corporate cultures, and place an uncommonly high value on relationships with people. And the histories of American Express, 3M, and Nokia suggest that companies can be quite successful by learning and re-learning relatively disparate technological skills—that is, by dramatically re-inventing themselves from time to time. What also stands out about these companies is that they come from very different industries, thereby suggesting that a firm's ability to re-invent itself is not unique to any particular industrial sector.

2.5.5 Limitations of Long-Term Relationships

It is important to underline, however, that the case for maintaining relationships with suppliers does have some limitations. Afuah (2000) points out that, if taken to extremes, maintaining supplier relationships in the face of innovation can seriously weaken a customer firm. And the literature also notes that the highly co-dependent firms within a Japanese *keiretsu* tend to be considerably less profitable than other Japanese companies like Sony or Honda that are far more independent (Tidd *et al.*, 2001). But there are instances in which it might be prudent not to underestimate the long-term value of these links. The evidence provided in this investigation is intended to suggest that industry clockspeed and the wellbeing of supplier relationships are additional variables that ought to be added to the existing system of classification. However, it is not attempting to supplant the variables and frameworks put forward thus far in the literature.

[12] Source: 3M's web site—http://www.3m.com/profile/looking/history.html (5 July 2002).

[13] Source: Nokia's web site—http://www.nokia.com/inbrief/history/early.html (5 July 2002).

2.6 The Role of Clockspeed

2.6.1 Defining "Clockspeed"

Fine (1998) points out that industries seem to evolve at different rates—that is, they operate at different "clockspeeds." Though hard to define precisely, an industry's clockspeed might be measured from the rate at which capital equipment becomes obsolete, the pace of organizational restructurings, or the rate at which brand names are established (Fine, 1998, pp. 17-18). Fine divides the range of potential clockspeeds into three groups: (1) fast clockspeed industries, e.g. PCs, software, athletic footwear, and semiconductors; (2) medium clockspeed industries, e.g. bicycles, cars, and fast food; and (3) slow clockspeed industries, e.g. commercial aircraft, tobacco, and petrochemicals.

However, if industries can have clockspeeds, perhaps people can, too. Tidd (1997) points out that establishing R&D-based links with other firms can be difficult. Relationships between people often take months or years to develop, and trust cannot be built overnight. Faster moving industries like the semiconductor sector, for example, might change and evolve so quickly that these links are seldom permitted to form, and trust-based, long-term relationships may not contribute measurably to a firm's success in those environments. At the other end of the spectrum, some industries that evolve extremely slowly—like the upstream oil and gas industry, for example—also might not benefit very much from long-term alliances. The rate of technological advance in these sectors might conceivably be so slow that an entire generation of managers and engineers would come and go in the time that it takes for the next wave of technology to be developed. It is therefore less likely that interpersonal relationships would play an important role in the development of innovations in these industries.

Harrigan (1984) also believes that the rate of technological change would impact a firm's make-buy decisions, and suggests that "[d]ifferent vertical integration strategies will be more appropriate if technology changes rapidly (or slowly)" (p. 644). Recent exploratory research focusing on the Dutch manufacturing industry has indicated that this is indeed the case: fast clockspeed firms tend to outsource a larger fraction of their total production value than companies in slower clockspeed industries (Akkermans, Meijboom, & Voordijk, 2003). But this work only analyzed the amount of outsourcing that companies engage in, and did not consider how supplier relationships might impact the development of innovations. There has not yet been any research to determine how industry clockspeed influences supplier relationships in R&D projects, leading to:

> ***Hypothesis 2:*** *Throughout the development of potentially radical innovations, only those firms with medium clockspeeds will benefit by establishing long-term relationships with their principal suppliers. Firms with either extremely slow or extremely fast clockspeeds will be relatively unaffected by these factors.*

2.7 Chapter Summary

This chapter began by exploring the systems of classification that have been applied in the technology management literature, and arrived at a definition for "radical innovation." It subsequently reviewed prior research in the area of outsourcing decisions and considered how radical innovations can shape make-buy strategies. Then it put forward two new hypotheses by introducing ideas from the areas of supplier relationships and industry clockspeed. The next chapter will outline the research methodology that will be used to test these hypotheses.

CHAPTER 3: RESEARCH METHODOLOGY

Having established in the previous chapter the hypotheses that will be tested in this investigation, this chapter will explain how they will be tested. It will begin by addressing the epistemological and philosophical foundations underlying the proposed methodology. Then it will discuss the strengths and weaknesses of case study research and survey-based research, and will explain why this project used both types. Lastly, it will explain the three-phase research design used in this investigation, and will discuss its limitations.

3.1 A Postpositivist Epistemological Foundation

The research design used to test any hypothesis in management science or operations research is influenced significantly by the philosophical point of view of the investigator. At a fundamental level lies a researcher's epistemological standpoint: are they a positivist or a relativist? A positivist essentially believes "that facts and values are distinct, and that scientific knowledge consists almost exclusively of observable facts" (Audi, 1999, p. 514). Simply put, this perspective holds that the world is as it is, and that a group of people can look upon a particular object or phenomenon and basically bear witness to the same thing. A relativist, by stark contrast, believes that facts and values are inseparable, and that both are involved in scientific knowledge (Audi, 1999). In other words, relativism basically maintains that all observations are firmly rooted in the perceptual, linguistic, and cultural aspects of the observer's personality. A corollary of this perspective is that there is no such thing as "absolute truth"—that is, one can never assume that other people can observe a phenomenon and consistently arrive at the same conclusion that you do.

Eisenhardt (1989) argues that positivism is a necessary beginning point en route to the "development of testable hypotheses and theory which are generalizable across settings" (p. 546). And, indeed, that is exactly what this investigation is intended to do. The hypotheses were tested by way of data collected from several companies, and patterns and themes were distilled from this evidence. Lying tacitly beneath this process is the basic belief that there is some kind of "larger truth" that data from multiple sources can converge on.

This is not to say, however, that this investigation or its findings can offer any kind of one-size-fits-all conclusion that suits every manager in every situation. The strategic landscape of any company is fraught with uncertainty and a broad range of largely unanswerable questions. Moreover, from an experimental point of view, it is very difficult to test hypotheses concerning the relationships of individual people or firms that reflect the marketplace or society as a whole (Epstein & Axtell, 1996). Significant generalizable research results are an elusive goal in the management sciences (Swink & Way, 1995). Therefore, in lieu of the relative rigidity of epistemological positivism, this investigation is rooted in postpositivism, a variant of positivism that more fairly reflects the naturally arising limitations of management or operations research.

Developed after World War II to offer a philosophical platform for quantum theory and disciplines of the natural sciences that were saddled with indeterminacy and uncertainty, postpositivism is grounded in the idea that reality exists but can never be completely understood or explained (Fischer, 1998; Wilson & Vlosky, 1997). Simply put, postpositivists argue that "reality can never be fully apprehended, only approximated" (Guba, 1990, p. 22). Thus, in light of the inherent difficulties of management research, the postpositivist epistemological approach was chosen as a foundation for this investigation. The purpose of this study is not to establish absolute truths or to make deterministic predictions; rather, it is to shed light on whether certain make-buy strategies can improve the *probability* of success throughout the introduction of a radical innovation. The lessons learned in this thesis would certainly not hold true in every scenario. However, as von Hippel (1988, p. 5) suggests, we need not necessarily understand everything about the market in order to understand the roles of supplier relationships and industry clockspeed usefully well, or to make predictions that are correct usefully often. No single approach to outsourcing radical new technologies will prevail every time, but "at least the odds in favour of successful innovation can be improved" (Tidd *et al.*, 2001, p. 45).

3.2 The Role of Contingency Theory

The success or failure of a firm is frequently assumed by management researchers to be a result of what the firm does or does not do (Hawawini, Subramanian, & Verdin, 2000; Rumelt, 1991). However, a company's performance can often be attributed to outside strategic trends and forces that are entirely out of its control (Henderson & Mitchell, 1997; McGahan & Porter, 1997; Powell, 1996; Schmalensee, 1985). The issue of which strategy to apply to a new technology should therefore be contingent on an industry's specific circumstances, and contingency theory is therefore also an important philosophical underpinning of this dissertation.

Established principally as a response to classical theories extolling "one best way" to manage a business (Tosi & Slocum, 1984), contingency theory is based on the belief that there is no single panacean approach to managing a firm. Instead, this philosophy suggests that "there is one best way given a certain type of operating environment" (Young, Parker, & Charns, 2001, p. 74). Contingency theory has been frequently applied in business and operations research (e.g. Fisher, 1998; Leiblein, Reuer, & Dalsace, 2002; Primo & Amundson, 2002; Shenhar, 2001), and more specifically in the technology management literature (e.g. Downs & Mohr, 1976; von Hippel, 1988).

Chapter 2 established that the main contribution of this investigation is to extend the current scheme of categorization used to analyze make-buy decisions in new technology environments. Thus, by adding new criteria by which to classify firms, this research develops contingent approaches to technology management by identifying new "certain types of operating environment" in which a manager might find himself.

3.3 The Motive for Using Case-Based and Survey-Based Research in Tandem

Most management or operations research tends to be based on either an exclusively qualitative research methodology or an entirely quantitative one. Each has strengths and advantages over the other. On one hand, quantitative studies "'persuade' the reader through de-emphasizing individual judgment and stressing the use of established procedures, leading to more precise and generalizable results" (Miles & Huberman, 1994, p. 41). Proponents of quantitative methods frequently defend this approach with "Kelvin's Dictum: 'When you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind'"[14] (McCloskey, 1985, p. 7).

On the other hand, advocates of qualitative research methods say that qualitative methods "often provide a good understanding of the dynamics underlying the relationship, that is, the 'why' of what is happening. This is crucial to the establishment of internal validity" (Eisenhardt, 1989, p. 542). Mintzberg (1979) also defends this approach, saying that "it is the anecdotal data that enable us to do the building. Theory building seems to require rich description, the richness that comes from anecdote. We uncover all kinds of relationships in our hard data, but it is only through the use of this soft data that we are able to explain them" (p. 587). Porter (1991) notes that "[a]cademic journals have traditionally not accepted or encouraged the deep examination of case studies, but the nature of strategy requires it. The greater use of case studies in both books and articles will be necessary for real progress at this stage in the field's development" (p. 99). Miles (1979) adds that qualitative data "offer a far more precise way to assess causality in organizational affairs than arcane efforts like cross-lagged correlations" (p. 590).

Drawing on the strengths of both methodological approaches, a number of researchers advocate the combined use of both quantitative and qualitative techniques (Meredith, 1998; Mingers & Brocklesby, 1997; Platts, 1993; Sieber, 1973). This tandem approach has been used on numerous occasions both within the management literature (e.g. Shenhar, 2001; Van Maanen, 1975; Wilson & Vlosky, 1997) and in other disciplines (e.g. LaPiere, 1934; Reiss, 1968). Using both research designs together effectively "enhances our belief that the results are valid and not a methodological artifact" (Jick, 1979, p. 602).

Miles & Huberman (1994) outline a multi-stage research methodology that "alternates the two kinds of data collection, beginning with exploratory fieldwork, leading to the developing of quantitative instrumentation, such as a questionnaire. The questionnaire findings can be further deepened and tested systematically with the next round of qualitative work" (pp. 41-42). This three-stage approach, shown in Figure 3.1, was particularly appropriate for this investigation because the early phases of the research entailed the development of new research questions. The process of discussing and refining the hypotheses with exploratory case studies and interviews with outside academics was therefore an essential beginning point.

[14] An approximation of Kelvin's Dictum is inscribed on the front of the Social Science Research Building at the University of Chicago, a longtime stronghold of quantitative research in that field (McCloskey, 1985).

A questionnaire was then used to test these hypotheses across a broad range of business units, thereby contributing to a greater degree of confidence in the generalizability of the results.[15] But as Miles (1979) suggests, any correlations arising from the questionnaire results would not demonstrate causality—that is, they would not shed light on the ultimate causes of the phenomena being studied. To this end, a final stage of qualitative case studies was included to "capture a more complete, *holistic*, and contextual portrayal" (Jick, 1979, p. 603) of the business units being studied. As Meredith (1998) contends, the addition of case study data after the survey phase "allows the much more meaningful question of *why*, rather than just *what* and *how*, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon" (p. 444).

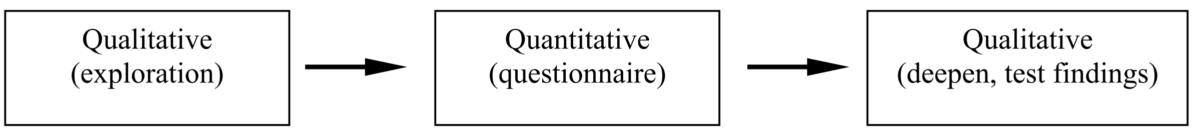

Figure 3.1: Three-Phase Research Design Linking Qualitative and Quantitative Data [Adapted from Miles & Huberman (1994, p. 41)]

3.4 Phase 1: Qualitative Exploration & Development of Hypotheses

The research questions presented in Chapter 2 originally began as loosely defined themes arising from the synthesis of prior work in the fields of make-buy decisions, supplier relationships, and industry clockspeed. The first phase of this investigation was consequently designed to tighten and re-shape these broad themes into workable, relevant hypotheses.

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[15] As the philosopher David Hume points out with his "Scandal of Induction," however, past events do not necessarily offer an infallible prediction of the future. Hume argues that we cannot be certain that the sun will rise tomorrow just because it did so today, noting that "even if experience has told us that past futures resembled past pasts, we cannot conclude that future futures will resemble future pasts—unless we already assume that the future resembles the past" (Honderich, 1995, p. 378). Nonetheless, we can say with great certainty from past experience that we would expect it to happen that way again. If past events could never tell us anything about the future, it could be argued quite forcefully that almost any kind of empirical research would be pointless. Thus, this investigation is rooted in the firm belief that past events can indeed offer some insight into how future events will unfold.

As suggested by King *et al.* (1994), the early days of the hypothesis-building process tend not to be straightforward or linear; instead, the hypotheses in this investigation evolved and changed over a six-month period. Early concepts and ideas were shared with decision-makers in industry and academics from other universities. These discussions resulted in new insights that led to the introduction of new literature and ideas into the research. These in turn led to modifications in the hypotheses, which were then discussed again with more academics and managers. Kolb *et al*. (1979) underline the value of iterative refinement throughout the theory building process. In "Kolb's Cycle," shown below in Figure 3.2, (1) a concrete experience is followed by (2) observation and reflection, which leads to (3) the formation of abstract concepts and generalizations, which lead to (4) hypotheses to be tested in future action, which in turn lead to new experiences. This piecewise process for making observations and theories was used to converge on the hypotheses at the core of this investigation.

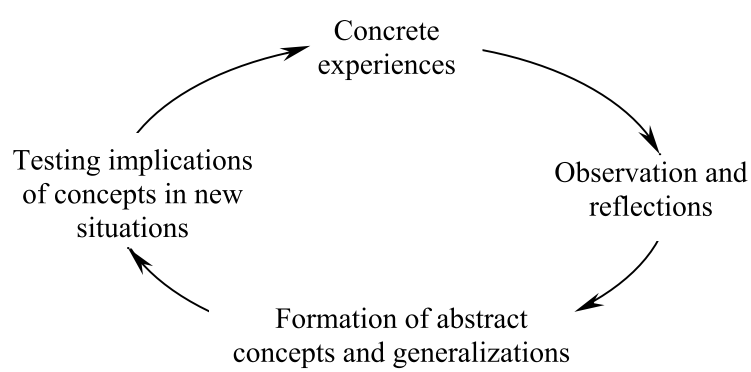


Figure 3.2: Experiential Learning Cycle
[Adapted from Kolb *et al*. (1979, p. 37)]

Each of the discussions was loosely guided by a list of questions, shown in Appendix A, but frequent departures from this agenda were made in the interest of exploring new and particularly interesting points raised in the course of each interview. Unconstrained by the rigid limits of questionnaires, case study data based on semi-structured interviews and discussions "can lead to new and creative insights [and the] development of new theory" (Voss, Tsikriktsis, & Frohlich, 2002, p. 195). The format of the discussions was adapted and changed from one site to the next to accommodate the constraints and limitations of each situation. More formal roundtable discussions were facilitated in larger groups, whereas smaller, informal interviews were conducted when only one or two managers were available. The managers and academics consulted throughout this phase of the research were chosen largely because of accessibility: every firm or university that was approached had been previously exposed on a professional level to the researcher. Discussions were arranged with senior managers and executive-level decision-makers from five companies:

- Intel Corporation
- Shell International Exploration & Production
- Domino Ink Jet Printing
- British American Tobacco
- Rolls-Royce

Towards identifying differences in make-buy decisions arising from industry clockspeed, the above list consists of fast (Intel), medium (Domino), and slow (Shell, BAT, and Rolls-Royce) clockspeed firms. Feedback and suggestions about the hypotheses and research design were also solicited from academics at:

- University of Brighton
- Massachusetts Institute of Technology

3.5 Phase 2: Quantitative Testing of Hypotheses Using a Questionnaire

3.5.1 Sample Selection and Survey Logistics

To test the two hypotheses, a survey was designed which asked senior managers about the make-buy strategies they applied during radical technology jumps in the past, and then measured the managers' perceptions of how their business unit is currently performing relative to its competitors. The overarching objective of the survey was to establish if there is a statistically significant link between a business unit's approach to make-buy decisions in the face of past radical innovations and the subsequent relative success or failure of that business unit. A "business unit" was defined as an organization that produces a particular line of products (as opposed to a corporation, which might consist of several business units and manufacture several different types of relatively dissimilar products).

The survey instrument, shown in Appendix B, was designed and implemented using guidelines from Dillman's (1978) "Total Design Method." As suggested by Oppenheim (1992), the instrument was pre-tested by three academics and three senior managers in industry, and was subsequently sent in the spring of 2003 to director-level decision-makers in manufacturing business units. The names and contact details of the managers were purchased from a firm that specializes in business-to-business direct mailing lists.[16] The pool of potential respondents included individuals whose job description fell into one of the following categories:

- Managing Director
- Joint Managing Director
- Deputy Managing Director
- Development Director
- Director of Engineering
- Operations Director
- Production Director
- Purchasing Director
- Technical Director
- Research Director

Selecting a sample of potential respondents from a direct mailing list does result in a population frame from a widely available source, thereby following the principle suggested by Forza (2002, p. 164) to make experiments reproducible. But this approach necessarily exposes the research design to a host of methodological dilemmas. First, it is impossible to establish the method of selection used by the direct mailing firm. Vidich & Shapiro (1955) underline the importance of avoiding bias in a sample, but there is no way to say for certain that the direct marketing firm's sampling process was absolutely random.

Second, as noted by Nicholls-Nixon & Woo (2003), even though the surveys and accompanying letters were sent to specific individuals within each business unit, one cannot be certain that every question was answered entirely and exclusively by that person. The intended recipient may have consulted others before arriving at a final answer to a particular question. And in light of the obvious time demands placed upon a director-level manager in a company, it is entirely possible that the entire survey could have been handed to someone else within the organization.

[16] An electronic database of names and addresses was purchased from Kompass UK, a company that describes itself on its internet site as "leading providers of privately collected business information, in over 70 countries." Visit www.kompass.co.uk for more information.

Third, this research strategy necessarily confines the analysis to those firms that survived the jump to the new technology. Directors of surviving firms will surely be able to recall some of the more memorable aspects of their competitors over the years, but it is clearly impossible to learn directly from firms that no longer exist. In spite of these shortcomings, however, the direct mailing list approach was chosen because of the large number of director-level contacts it offered from a broad range of disparate manufacturing business units.

The total mailing list of 3,000 potential respondents was evenly divided into two groups: (1) 1,500 directors from UK-based business units, and (2) 1,500 directors from all over the world. Each director in the UK-based group was sent a paper copy of the survey with a letter of introduction, shown in Appendix C. The respondents were asked to return their completed questionnaire in a freepost envelope. A reminder postcard, shown in Appendix E, was sent one week later. Finally, three weeks after the initial mailing, a second letter—complete with a new copy of the survey and another freepost envelope—was sent to directors who had not yet replied. This second follow-up letter is shown in Appendix G.

The financial and logistical difficulties of international freepost reply envelopes made it quite hard to apply this same methodology to the international group, however. Citing similar challenges, Dillman (2000) designed a "survey which used no paper or stamps, but did use individually addressed e-mails and a pre-notice with three replacement questionnaires, [and] achieved a 58 percent response rate. This response rate was the same as that obtained by a four-contact paper mail strategy" (p. 4). Based on the success of this experiment with electronic media in lieu of paper, a WWW-based version of the survey, shown in Appendix I, was developed to accommodate international respondents. The online version closely mimicked the layout of the paper questionnaire, and contained exactly the same questions. As shown in Appendix D, signed letters asking potential respondents to participate in the online survey were sent via airmail at the same time the paper questionnaires were distributed. Reminder postcards and follow-up letters, respectively shown in Appendices F and H, were also sent according to the same schedule. To restrict access to the WWW site to the intended audience, each letter to the international respondents included a user identification number and password.

But using the internet to collect data from respondents all over the world gave rise to several weaknesses in the research design. First, Dillman (2000) underlines that, in spite of the internet's proliferation in most parts of the world, it is unlikely that every potential respondent would have an even measure of access to the WWW (p. 220). The medium used to deliver the survey may therefore influence the types of business units that respond. High technology companies might, for example, be over-represented in the sample, while managers from less internet-savvy industries like heavy manufacturing might not find it quite as easy to participate.

Second, people from different cultural backgrounds may have profoundly different interpretations of the relationships and inter-firm links discussed in the survey. As Litwin (1995) suggests, "failing to be attentive to multicultural issues may result in significant bias when collecting data" (p. 70). In her investigations focusing on trust among firms in different countries, Sako (1998) notes that some cultures seem to be significantly more predisposed to trust than others (p. 105). It therefore follows that a respondent's answers throughout the survey could be significantly coloured by where they are from. But in the interest of focusing on the principal hypotheses of the investigation, the WWW-based survey did not separate respondents according to nationality.

Third, there can be little doubt that some of the international respondents would have a limited knowledge of English. Nonetheless, a WWW-based survey was used on the expectation that director-level managers of internationally recognized companies would probably have access to the internet, and that many of them would have a working knowledge of English.

To create an international sample pool that was reasonably representative of manufacturing business units around the world, the database of potential respondents for the WWW-based survey was drawn from four geographic regions: the USA, Western Europe, Asia/Pacific, and the rest of the world. The number of potential respondents in each region was proportional to the total gross domestic product (GDP) of its constituent countries.[17] For example, the aggregated GDP of Western Europe represents approximately 21 percent of the world's total economic output and 319, or 21 percent, of the 1,500 managers in the international database were therefore from that region. The overall breakdown of the sample is shown in Figure 3.3.

[17] Source: the US Central Intelligence Agency web site—http://www.cia.gov/cia/di/products/hies/graphics/figure04.pdf (12 February 2003). These figures reflect conditions in 1997.

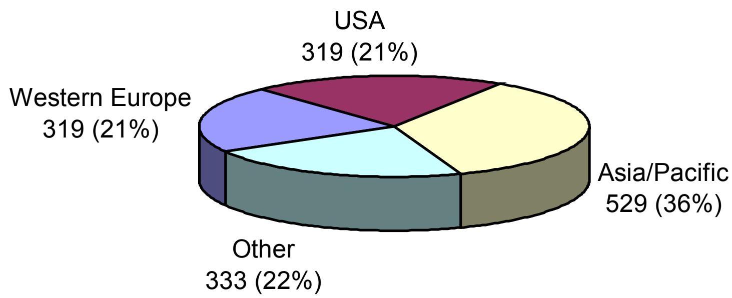


Figure 3.3: Breakdown of Potential International Respondents by Region

3.5.2 Applying a Common Definition of "Radical Innovation"

As discussed in Chapter 2, there are quite a few competing definitions of "radical innovation" both in the literature and in the day-to-day parlance of managers in the marketplace (McDermott, 1999, p. 632). Accordingly, an important aspect of the survey was to normalize the resulting data by ensuring that all the respondents were applying the same definition of radical innovation outlined earlier. Two mechanisms were put in place to ensure that the survey respondents were providing information about only those technology jumps that are in line with Afuah's (1998) definition. First, an explanatory paragraph was offered at the beginning of the survey instrument to underline the organizational focus of the definition being used throughout the questions, and to spell out with a real-world example exactly what the telltale signs of such a jump might be:

> A competence-destroying technology typically shifts the fundamental skills and knowledge base of an industry. It often results in the introduction of new firms and fundamentally new product architectures and standards in the market. The leap from typewriters to word processors is one example of this kind of shift, as is the move to DVDs from videocassettes.

Second, via a series of eight tick box questions, respondents were asked about several definitional aspects of each of the technology jumps they put forward. The first tick box asked the respondent to indicate whether or not the innovation satisfied the precise organizational criteria established by Afuah (1998). This box was an indirect means by which to double-check that the technology jump suggested by the respondent explicitly satisfied not only the spirit but also the precise letter of the definition being used for this study.

3.5.3 Dependent Variables

The success of responding business units was measured using four Likert-type 1-5 scales. Towards establishing the construct validity of a survey—that is, to make sure that the variables in the survey fairly represent the theoretical constructs being measured—Forza (2002) encourages the use of variables and definitions that "have already been developed, used, and tested" (p. 159). Thus, the dependent variables used in this survey were distilled from prior investigations in similar contexts. The first measure of success, the business unit's relative revenue market share compared to its direct competitors', was used as a reflection of performance by Afuah (2001). The other three measures of success—relative average profitability over the last three years, relative overall sales growth, and relative overall financial performance—were used by Powell (1996).

Perception-based scales were used to estimate each business unit's relative position according to each of the criteria. While some researchers have expressed reservations about measurements based on perceptions (e.g. King *et al.*, 1994; Sutcliffe & Weber, 2003), perception-based measures have been used in management research (e.g. Brouthers & Xu, 2002; Delaney & Huselid, 1996; Hunton, McEwen, & Wier, 2002; Nicholls-Nixon & Woo, 2003). Financial results from business units within publicly traded companies are usually aggregated with those of all the other units within the firm, and perception-based measurements were therefore used in this investigation to assess outcomes at the business unit level. Powell (1996) argues that "[p]erceptually based research is rare in industry studies, but executive perceptions have been used extensively in organizational research, and their use has been justified elsewhere" (p. 326). Defending this practice further, he points out that:

> Although executives' perceptions do not necessarily parallel objective measures of corresponding phenomena... perceptions may be more discriminating than objective measures, and they almost certainly have more influence on executive decisions… Because executives' perceptions influence organizational behaviour, they are an important organizational variable in and of themselves. Of course, executives do make mistakes and perceive the same phenomena differently... but "perception" does not necessarily equate with "bias." Indeed, one could argue that executives' biases do not exceed those embodied in accounting reports or 4-digit SIC[18] codes, which contain… incontrovertible biases and distortions (p. 326).

[18] SIC stands for Standard Industrial Classification, a system formerly used by the US Government to classify organizations by their primary type of activity. This coding system has since been replaced by the North American Industry Classification System (NAICS).

3.5.4 Independent Variables

While trust and interpersonal relationships might play a key role in the success of some supplier relationships, they are both abstractions that can be difficult to measure directly with any degree of reliability or repeatability. Researchers in these areas have pointed to several factors that play a significant role in creating trust between business units, and that may therefore act as a more measurable proxy for various aspects of these types of relationships. Measured using Likert-type 1-5 scales similar to those used by Zaheer *et al.* (1998) to quantify trust, the proxy variables and their relevance to building trust and long-term relationships are as follows.

New Suppliers: Firms that stay with existing suppliers in lieu of new ones can develop long and fruitful relationships that are based on trust and mutual understanding (Womack *et al.*, 1990). A positive correlation with the dependent variables would suggest that longer relationships are beneficial to the business units concerned. Scale: 1 = after introduction of competence-destroying technologies, business unit dropped/changed all principal suppliers; 5 = after introduction of competence-destroying technologies, business unit kept all principal suppliers.

Outsource: Sharing a long-term, trust-based relationship with a supplier would entail not keeping a new technology in-house in its early days (Quinn, 1999). A supplier can best contribute to the new technology and to its customer relationships if it is included from the outset in the development of the innovation. A positive correlation with the dependent variables would support this perspective. Scale: 1 = business unit initially retained in-house all skills and equipment required for new technologies; 5 = business unit initially outsourced all skills and equipment required for new technologies.

Able to Learn: The success or failure of a business unit's move to a new technology often hinges on the ability of its suppliers to learn the new skills underlying the innovation (Afuah, 2000). A positive correlation with the dependent variables would confirm that the ability of suppliers to learn new skills quickly plays a significant role in a firm's transition to a new technology. Scale: 1 = existing suppliers are unable to learn the new skills underlying competence-destroying technologies; 5 = existing suppliers are able to quickly learn the new skills underlying competence-destroying technologies.

Values Relationships: Business units that place a high value on long-term relationships with suppliers frequently do better than those who do not (Dyer, 1996; Eisenhardt & Schoonhoven, 1996; Womack *et al*., 1990). A positive correlation with the dependent variables would indicate that these priorities lend themselves to better performance. Scale: 1 = business unit places less value on long-term supplier relationships than competitors do; 5 = business unit places more value on long-term relationships than competitors do.

Costs Borne by Suppliers: A supplier's willingness to invest in a particular technology is an attractive incentive for a prospective technology partner (Cáñez & Probert, 1999; Kumpe & Bolwijn, 1988; Leonard-Barton, 1995; Manders & Brenner, 1995). A positive correlation with the dependent variables would suggest that it is prudent to invest financially in relationships focused on the co-development of new technologies. Scale: 1 = suppliers bear none of the costs associated with acquiring new technologies; 5 = suppliers bear all the costs associated with acquiring new technologies.

Past Role: Past exposure to problem solving with suppliers will cause managers to trust each other more and interact more productively (Sako, 1998). A positive correlation with the dependent variables would show that this type of previous exposure to suppliers contributes to success. Scale: 1= suppliers played no role whatsoever in the development of new technologies in the past; 5 = suppliers played a very important role in the development of new technologies in the past.

Future Role: Similar to "Past Role," this variable determines how important a role suppliers will play in the development of new technologies in the future. A positive correlation with the dependent variables would point to a long-term benefit for business units whose managers espouse this outlook. Scale: 1 = suppliers will play no role whatsoever in the development of new technologies in the future; 5 = suppliers will play a very important role in the development of new technologies in the future.

Change in Strategy: Business units may use their suppliers exclusively for their additional manufacturing capacity, thereby losing out on the benefits that might be gained by involving them in the R&D process (Fine, 1998; Piachaud, 2000; Quinn, 2000; Quinn & Hilmer, 1994). Managers behaving in this way would be regarding their supply base as a source of production capacity instead of innovation. A negative correlation with the dependent variables would suggest that business units perform better by maintaining relationships with their suppliers throughout the nascent and mature phases of a technology's lifecycle. Scale: 1 = business unit is more likely to bring technology in-house as it matures; 5 = business unit is more likely to outsource technology as it matures.

3.5.5 Control Variables

Clockspeed: Business units were separated according to the rate of change of product technologies within their respective industries. Based on guidelines offered by Fine (1998), sectors that significantly change product technologies every two years or less were categorized as "fast." Business units who introduce new product technologies every two to five years were labelled as "medium." Respondents from industries who introduce major new product technologies at intervals greater than five years were categorized as "slow."

Number of Employees: Whereas a small business unit might have trouble maintaining supplier relationships in the face of adverse circumstances, a larger business unit might be able to endure short-term hardship in the interest of preserving its supplier links for the long-term. The size of a business unit may have a pronounced impact on its strategic decisions (Leiblein *et al.*, 2002). A measure of the total employee headcount within the business unit was accordingly included as a control variable.

3.5.6 Determining Respondents' Industry Clockspeed

An industry's clockspeed is neither immediately obvious nor universally defined. However, Fine (1998) specifically points to three determining factors: (1) the rate at which an industry introduces substantial new product technologies, (2) how often firms within the industry are subjected to major organizational changes, and (3) the rate of evolution of the industry's process technologies. The first determinant, the rate of change for product technologies, was used as the deciding variable in this study because it is the most visible and verifiable to people outside of the sector being affected by the technology change. For example, the average consumer was personally able to bear witness to the shift from typewriters to PCs in the 1980s, but the organizational impact that this change had on firms like Olivetti or IBM has gone largely unobserved by almost everyone but industry insiders.

Fine (1998, p. 239) offers several real-world examples that capture the essence of fast, medium, and slow clockspeed industries. Based on the rates of change outlined in these examples, Table

3.1 outlines the boiled-down definitions for each clockspeed category that were applied throughout the analysis of the survey data. One business unit from the UK sample did not provide an answer as to how frequently it introduces significant product technologies. Other information from this particular respondent made it clear that they were from the electronics industry, however, and Fine explicitly identifies the electronics sector as belonging to the fast clockspeed group. This data was therefore put into that category based on this secondary information. Similarly, one responding business unit from the international survey sample also did not indicate how often it introduced new product technologies, but the respondent indicated that he worked for an "agritech" company. Fine identifies agricultural firms as belonging to the medium clockspeed category, and this business unit was classified correspondingly.

Clockspeed Category	Years Between Introduction of Major Product Technologies
fast	0-2.0
medium	2.1-5.0
slow	5.1+

Table 3.1: Definition of Clockspeed Categories

3.6 Phase 3: Qualitative Deepening of Results

The relative rigidity of the survey does very little to explain either the causality or the trends that might become apparent in the data. Thus, the third phase was designed to add "the more complete, *holistic*, and contextual portrayal" (Jick, 1979, p. 603) that qualitative research methods can provide. Simply put, Phase 3 was used to rationalize and help explain the results of the survey.

Three responding business units were chosen from the original sample of 3,000, and in-depth case studies were conducted at each during the spring and summer of 2003. Eisenhardt (1989) recommends using between four and ten case studies for the theory building process, but the role of the case studies in Phase 3 was not to contribute to the development of new theory; rather, they were only intended to explain observations made in earlier phases of the investigation. To shed light on differences in make-buy decisions or supplier relationships arising from industry clockspeed, case studies were selected from firms in each of the three clockspeed groups:

- Intel Corporation (fast clockspeed)
- Domino Printing Sciences (medium clockspeed)
- Twister BV (slow clockspeed)

Voss *et al.* (2002) suggest that case studies should be rigorously selected such that they represent a broad range of subjects that dramatically highlight the variables being studied while "controlling for performance on others" (p. 203). While methodologically pure, however, this approach proved somewhat more challenging in practice. Each of the chosen cases was taken from firms that were fairly representative of their respective clockspeed groups in many regards but, as in Phase 1, the selection of case studies was also heavily influenced by the accessibility of these business units to the researcher.

Each case study consisted of a series of one-on-one interviews with personnel in each business unit who played a significant role in the outsourcing decision making process throughout the adoption of the radical innovation being studied. In the interest of keeping the discussions roughly in line with the hypotheses—a procedure advocated by several practitioners of case study research (e.g. Handfield & Melnyk, 1998; Miles, 1979; Yin, 1981, 1993)—a copy of the survey was used as a loose framework for each interview. In addition to providing a numerical answer for each Likert-type scale, each respondent was also asked to explain the circumstances and rationale behind their response.

Yin (1994) and Flick (1998) both recommend using multiple sources of evidence within each case study to "triangulate" among various points of view and minimize the amount of subjectivity within the study. The semi-structured interviews, which each lasted approximately one hour, were therefore conducted with between four and ten managers and senior engineers in each business unit. Each case study was then summarized in a written report and sent back to the interviewed parties for review and approval. Eisenhardt (1989) and Voss *et al.* (2002) point to this practice as an important step for improving the internal validity of case study research.

3.7 Chapter Summary

This chapter began by addressing the epistemological and philosophical foundations underlying the proposed research methodology. Then it discussed the strengths and weaknesses of case study research and survey-based research, and explained why this investigation made use of both types in a three-phase research design. The next chapter will present the results of the survey, and will determine whether or not the data support the two hypotheses.

CHAPTER 4: STATISTICAL ANALYSIS OF SURVEY RESULTS

The overarching objective of this chapter is to provide a statistics-based analysis of the data resulting from the survey outlined in the previous chapter. To this end, it will begin with an explanation of how the raw survey responses were interpreted and framed prior to further examination, and a review of the univariate and intercorrelation characteristics of the data. This chapter will also discuss the various statistical tools that were considered for analyzing the data, and will provide a justification for the approach that was eventually chosen. Lastly, it will directly determine whether or not the data supported the two hypotheses put forward earlier in the thesis.

4.1 Preliminary Analysis and Framing of Raw Data

4.1.1 Response Rate

Of the original 1,500 surveys sent out to UK manufacturers, 252 were returned incomplete. An overwhelming majority of these returned questionnaires were sent back because of outdated or incomplete mailing addresses. A few others were returned with explanatory notes indicating that the firm was not actually a manufacturer at all, that the intended recipient had moved on to another firm, or that the company simply preferred not to participate in questionnaires. The international sample yielded a similar result: 118 of the original 1,500 envelopes were sent back without any kind of response on the internet site. The reasons for their return were essentially the same as for the UK group, although one respondent explained in a letter written in French that he could not participate because he did not speak English.

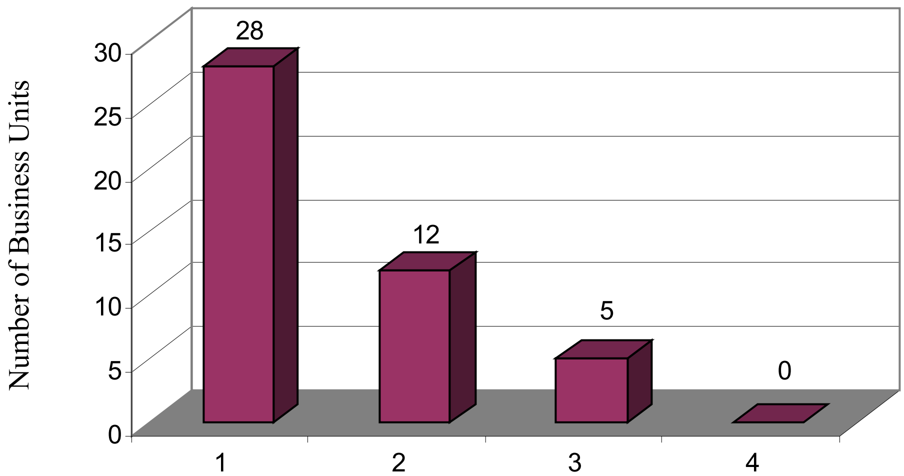
In total, 220 completed questionnaires were received from UK respondents. After eliminating envelopes that were returned incomplete, the amended return rate for the UK group was 17.6 percent. Similarly, a total of 235 people from the international group completed the WWW-based survey, resulting in an amended return rate of 17.0 percent. The relatively low response rates can probably be attributed to the fact that the surveys were entirely unsolicited and were sent without any kind of advance warning, in-person meeting, or telephone call. Also, the comparatively high rank of the target group—director-level managers and key decision-makers—are very often the kind of people who do not have time for non-essential activities such as questionnaires.

Unfortunately, however, the majority of the technology jumps did not satisfy the definitional criteria for "radical innovation" outlined by Afuah (1998). As noted earlier, respondents were presented with a series of eight tick box questions asking about several definitional aspects of each of the technology jumps they put forward. The first tick box asked the respondent to indicate whether or not the innovation satisfied the precise organizational criteria established by Afuah (1998). A total of 175 questionnaires from UK respondents and 204 participants from the international group were eliminated from the analysis because they did not tick the first box in the list.

4.1.2 Establishing the Individual Technology Jump as the Unit of Analysis

The survey invited respondents to share information and strategic approaches from up to four different transition periods involving radical technologies. But this relatively open-ended architecture in the survey design necessarily raises an important question with respect to the analysis of the data: what should be done about multiple responses from a single firm? As shown in Figure 4.1, 28 of the respondents from the UK sample discussed only one radical technology jump. However, 17 business units indicated that such a technology transition had occurred in their industries on more than one occasion, and gave information about each of them. Figure 4.2 tells a similar story for the international data set, with 12 out of 31 replying business units indicating that they had experienced more than one radical innovation leap in their respective industries.

The possibility of averaging multiple responses from each firm was explored, but was eventually rejected on the grounds that managers may have been faced with profoundly different circumstances in the marketplace with each technology jump, and may therefore have reacted



Number of Technology Leaps Described in Survey per Responding Business Unit

Figure 4.1: Number of Technology Leaps per Responding Business Unit (UK Sample)

quite differently in each of those instances. Moreover, because truly radical technologies are a relatively infrequent event in most industries, it stands to reason that the management team and competitive environment would have been markedly different from one technology jump to another. It therefore follows that averaging the responses from multiple jumps may have resulted not in a single representative figure, but in one number with very little meaning at all. This approach was rejected on these grounds.

Instead of looking at each business unit or company as the unit of analysis, Tatikonda & Rosenthal (2000) consider individual projects as separate data points even though many of the projects within the study came from the same company. This solution seems quite reasonable in light of the fact that different projects may be managed very differently within a single firm, and may in fact even be managed by entirely different groups of people. A similar philosophy was applied to the data in this thesis. Multiple radical technology jumps put forward by a single business unit were usually separated in time by several years, and would therefore almost certainly have been made under profoundly different sets of circumstances. The unit of analysis in this investigation consequently consists of specific instances in which business units dealt with radical technologies. Multiple responses from a particular business unit were regarded as independent data points.

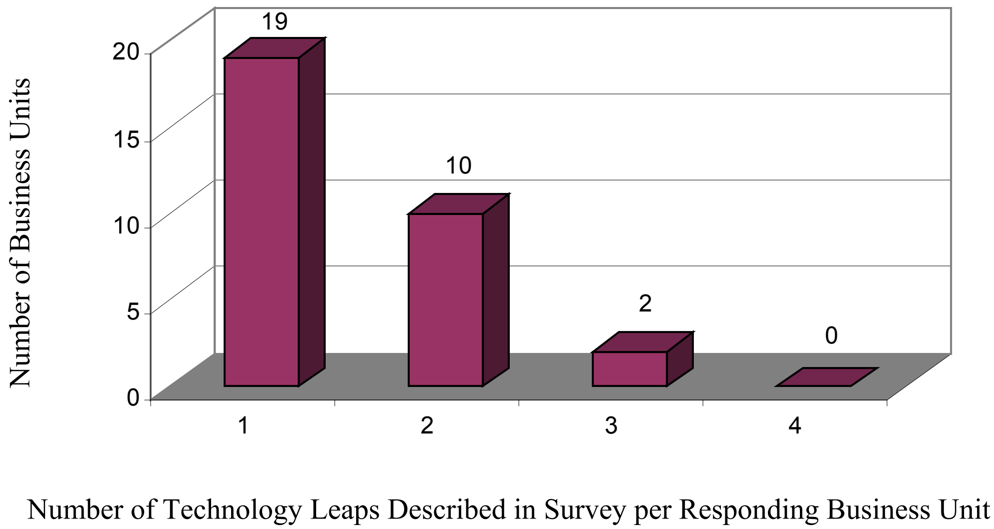


Figure 4.2: Number of Technology Leaps per Responding Business Unit (International Sample)

An obvious objection to this approach is that it might result in conclusions that are skewed towards the experiences and perspectives of firms that discuss multiple technology jumps, or that industries which are in a state of perpetual upheaval will have more of an influence on the overall outcome. This most certainly was a major consideration for Nicholls-Nixon & Woo (2003), who only have four instances in which multiple responses were received from a single firm. Because of the relatively small number of firms with multiple data points in that scenario, there was a very non-trivial probability that their results might have been unduly influenced by a small handful of firms. The situation for the survey data in this thesis is quite different, however, in that more than half of the individual technology jumps come from business units that discussed more than one radical technology transition. It can therefore be argued that any kind of over-representation brought about by multiple responses from a particular business unit would probably be balanced by multiple responses from several other firms from entirely different industries. Simply put, the problem is effectively self-correcting because multiple data points were offered by a relatively large number of firms from disparate industries.

4.1.3 Breakdown of Responses by Clockspeed

As shown in Figure 4.3, about 42 percent of the technology jumps in the UK sample came from fast clockspeed environments, while only 18 percent came from respondents in slow clockspeed industries. Figure 4.4 shows that this spread was even wider for international respondents: 66 percent were from fast clockspeed sectors, while only 7 percent—that is, three business units—were from slow clockspeed industries. Any conclusions drawn from a sub-group consisting of only three data points would be statistically meaningless, so the “slow clockspeed” category within the international survey data was subsequently excluded from the analysis.

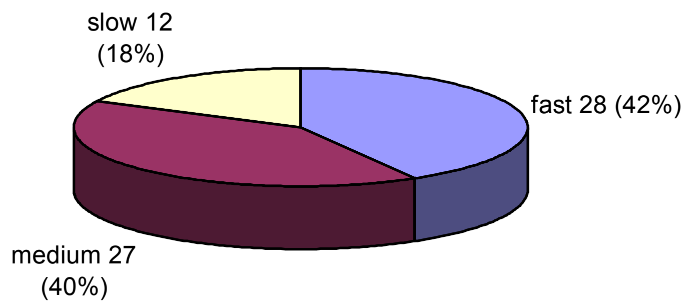


Figure 4.3: Breakdown of UK Technology Jumps by Clockspeed (n = 67)

4.1.4 Transformation of “Number of Employees” Variable

The “Number of Employees” variable within both the UK and international data sets was severely skewed on account of a small number of business units that were considerably larger than the rest. This extreme non-normal distribution of data represented somewhat of a problem where statistical analysis was concerned. In situations like these, variables are routinely transformed by various means in operations and management research to “reduce or remove problems of asymmetry, inequality of variance, or other abnormalities” (Forza, 2002, pp. 182-183). Hence, in the interest of converting this broad range of data into a form that more readily leant itself to statistical analysis, the “Number of Employees” variable was transformed by taking the natural logarithm of the original data.

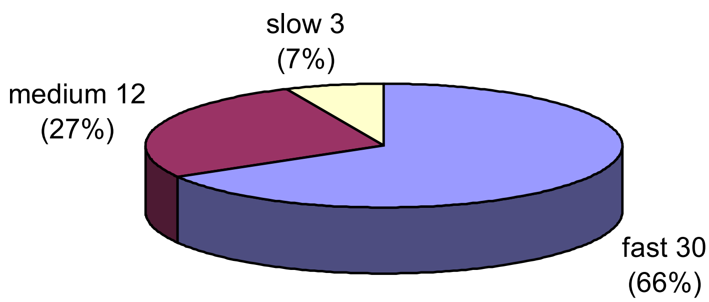


Figure 4.4: Breakdown of International Technology Jumps by Clockspeed (n = 45)

4.1.5 Rationalization of Spearman's ρ for Testing Hypotheses

Parametric statistical tools are generally preferred within the social and management sciences because they are generally more powerful in terms of their "sharpness" and their ability to support hypotheses (Levin, 1987, p. 627). There are, however, several assumptions that must be satisfied for parametric techniques to be appropriate (Forza, 2002, p. 183):

1) the observations must be independent—that is, the selection of any one case should not affect the chances for any other case to be selected in the sample
2) the observations should be drawn from normally distributed populations
3) the populations should have equal variance
4) the measurement scales should be at least interval so that arithmetic operations can be used with them

A data set is typically considered to be normally distributed if its skewness and kurtosis both fall within the range [-1, 1]. However, a univariate analysis[19] of both the UK and international data sets, respectively shown in Tables 4.1 and 4.2, shows that these criteria were not met. Also, via the rather substantial differences among the standard deviations of the variables, both the UK and international data sets seem not to satisfy the "equal variance" test. And in light of the fact that

[19] All the statistical analyses discussed in this chapter were performed using SPSS Version 11.5 for Windows.

multiple data points were taken from some of the responding business units, it is clear that the independence requirement is not met. These characteristics of the data set all point to the fact that, despite their obvious advantages, it would be inappropriate to use parametric analysis techniques for this data.[20]

Variable	Mean	Stan. Dev.	Skewness	Kurtosis
Relative Market Share	3.366	0.747	-0.535	-0.614
Relative Average Profitability	3.343	0.966	-0.228	-0.271
Relative Sales Growth	3.231	0.947	-0.175	-0.337
Relative Overall Financial Performance	3.291	0.946	-0.311	-0.297
New Suppliers	3.211	1.472	-0.265	-1.331
Outsource	2.604	1.462	0.350	-1.230
Able to Learn	3.175	1.464	-0.119	-1.369
Values Relationships	3.948	0.905	-0.440	-0.673
Costs Borne by Suppliers	2.239	1.280	0.646	-0.751
Past Role	2.791	1.357	0.130	-1.256
Future Role	3.052	1.283	-0.053	-1.081
Change in Strategy	2.687	1.261	0.481	-0.659
ln(Number of Employees)	3.725	1.473	0.699	-0.006

Table 4.1: Univariate Analysis of UK Data

The chi-square test is a popular tool for testing hypotheses with non-parametric data, and was duly considered for this investigation. But the test comes with criteria and requirements of its own: because of the transitional matrices involved in the calculation of this measurement,[21] the chi-square test is best applied to cases involving large numbers of data points. Due to the comparatively small number of data points involved, however, early attempts to use the chi-square test led to spurious results, and this method consequently had to be abandoned.

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[20] The rules for applying statistical tools are not entirely rigid, however, and parametric tools are sometimes liberally applied in contexts involving "nearly normal" data. Both parametric and non-parametric analyses were initially applied to both the UK and international data sets. If the Pearson (parametric) and Spearman (non-parametric) coefficients were sufficiently close at the end of the analyses, one could forcefully argue in favour of using parametric tools despite their imperfect fit. As shown in Appendix J, however, the two sets of coefficients are very different, and any ambitions towards using the more powerful parametric techniques were consequently cut short.

[21] A more thorough explanation of this problem can be found on CalTech's web site—http://nedwww.ipac.caltech.edu/level5/Wall2/Wal3_4.html (24 November 2003).

Variable	Mean	Stan. Dev.	Skewness	Kurtosis
Relative Market Share	3.581	1.277	-0.514	-0.840
Relative Average Profitability	3.289	1.074	-0.143	-0.616
Relative Sales Growth	3.511	1.180	-0.332	-0.839
Relative Overall Financial Performance	3.467	1.095	-0.594	-0.529
Clockspeed	1.400	0.618	1.307	0.712
New Suppliers	2.733	1.529	0.314	-1.306
Outsource	2.911	1.621	0.083	-1.603
Able to Learn	3.133	1.618	-0.158	-1.579
Values Relationships	4.011	1.264	-1.229	0.613
Costs Borne by Suppliers	2.700	1.471	0.159	-1.392
Past Role	3.111	1.402	-0.154	-1.242
Future Role	3.378	1.284	-0.288	-0.969
Change in Strategy	2.800	1.424	0.172	-1.300
ln(Number of Employees)	4.468	1.622	-0.121	-1.116

Table 4.2: Univariate Analysis of International Data

The Kruskall-Wallis test is another popular variety of non-parametric tool that was considered for testing the hypotheses put forward in this investigation. It is a one-way measure of analysis of variance that is commonly applied to situations in which at least one of the variables is assumed to consist of ordinal data—like, for example, those resulting from Likert-style scales. But this test was rejected in favour of Spearman's ρ, a measure of correlation between two ordinal variables that has been used extensively both by researchers in the domain of operations and management (e.g. Bukchin, 1998; Tamosaitis & Schwenker, 2002) and in related fields like economics (e.g. Dowling & Cheang, 2000; Neumayer, 2002). Because almost all of the data in the survey is ordinal in nature, Spearman's ρ correlation was considered to be more powerful as an analytical tool in this particular instance.[22] Moreover, Spearman's ρ is entirely unaffected by logarithms or squaring (Cooper & Emory, 1995, p. 507), and is therefore not distorted by the transformation of the "Number of Employees" variable.

Because of the relatively small number of data points in the sample and their non-normal distributions, more sophisticated tools like multiple regression analysis, structural equation modelling, Chronbach's alpha, and factor analysis would not credibly contribute to the examination of this data.

[22] Source: Dr. Brian Faragher, Senior Lecturer in Statistics at the University of Manchester Institute of Science and Technology (UMIST) and a Fellow of the Royal Statistical Society. Personal communication with author, 28 November 2003.

4.1.6 Imputation of Missing Data

A common problem in statistical analyses is that of missing data. As a response to this, the imputation of data "holes" is an area of statistics that has progressed appreciably since the 1980s, and that now offers several different types of solutions. The practice of imputation has become so widespread, in fact, that many statisticians today consider it to be less detrimental to the analysis process than simply deleting or ignoring incomplete data sets.[23] Missing data points were replaced with values calculated by the expectation maximization (EM) algorithm. A relatively common and widely accepted approach to imputation, EM essentially uses data from the population to establish the most likely response for the missing data elements.

However, prior to applying any kind of imputation algorithm, it is important first to establish that the missing data points are distributed randomly throughout the data set. Little's MCAR ("missing completely at random") is a measure that fulfils this purpose. The MCAR significance measure for both the UK and international data survey sets was 1.000, which indicates that there was no discernible pattern to the missing responses in either group. Imputation can therefore reasonably be applied to both data sets.

	UK (n = 67)		International (n = 45)	
Variable	**Count**	**Percentage**	**Count**	**Percentage**
Relative Market Share	0	0	4	8.9
Relative Average Profitability	0	0	2	4.4
Relative Sales Growth	0	0	2	4.4
Relative Overall Financial Performance	0	0	2	4.4
New Suppliers	0	0	0	0
Outsource	0	0	0	0
Able to Learn	0	0	0	0
Values Relationships	0	0	1	2.2
Costs Borne by Suppliers	0	0	1	2.2
Past Role	0	0	1	2.2
Future Role	0	0	1	2.2
Change in Strategy	0	0	1	2.2
ln(Number of Employees)	3	4.5	3	6.7

Table 4.3: Breakdown of Missing Data

[23] Source: North Carolina State University's web site—
http://www2.chass.ncsu.edu/garson/pa765/missing.htm (8 December 2003).

As shown in Table 4.3, there were only three missing data points in the UK sample, and they all occurred within the "Number of Employees" variable. The international data set, by stark contrast, had considerably more missing data points. Three variables in the international data set had no missing points at all, but the "Relative Market Share" variable was missing almost 8.9 percent. The rest of the variables fell in between these two extremes.

4.1.7 Bivariate Intercorrelations

Tables 4.4 and 4.5 present the bivariate intercorrelations for both the independent and dependent variables. The results show a strong association between all four of the independent variables in both the UK and international data sets, suggesting that success according to one of the proposed measurements of performance is typically a good predictor of success in all of them.

The extremely high intercorrelation between the "Past Role" and "Future Role" variables in both the UK and international data sets indicates that respondents do not expect a significant change in how their principal suppliers will contribute to the development of new technologies. This very high association reveals a deeply rooted belief that the role of suppliers in the development of past innovations will faithfully reflect the role that they will play as new technologies are developed in the future.

4.2 Testing the Hypotheses

4.2.1 Hypothesis 1: Close Supplier Relationships Result in Better Performance

Overall, Tables 4.6 and 4.7 show that the UK and international data sets both offer a very weak degree of support for this hypothesis. Only one of the independent variables, "Values Relationships," was meaningfully linked to the long-term performance of UK respondents. This variable was significantly correlated at the $p < 0.05$ level for three of the success indicators. No such connection appeared in the international data, however. The rest of the independent variables are either not statistically relevant at all, or only relevant for one of the success indicators out of the four.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Relative Market Share	1												
2 Relative Average Profitability	0.573**	1											
3 Relative Sales Growth	0.569**	0.594**	1										
4 Rel. Overall Financial Perf.	0.620**	0.833**	0.709**	1									
5 Clockspeed	-0.029	-0.331**	-0.020	-0.324**	1								
6 New Suppliers	0.001	-0.079	0.020	-0.017	0.124	1							
7 Outsource	0.008	0.048	0.031	0.105	-0.146	0.242*	1						
8 Able to Learn	-0.112	-0.067	-0.067	-0.133	0.102	0.493**	0.030	1					
9 Values Relationships	0.262*	0.226	0.261**	0.288*	-0.154	0.149	0.176	0.076	1				
10 Costs Borne by Suppliers	-0.168	-0.326**	-0.230	-0.234	0.286*	-0.188	-0.196	-0.259*	-0.079	1			
11 Past Role	-0.140	-0.154	-0.212	-0.165	0.032	-0.417**	-0.136	-0.498**	0.151	0.422**	1		
12 Future Role	-0.175	-0.102	-0.219	-0.119	-0.001	-0.235	-0.060	-0.293*	0.334**	0.337**	0.806**	1	
13 Change in Strategy	-0.174	0.080	-0.119	0.035	0.089	0.022	0.061	0.013	-0.024	-0.046	-0.025	-0.113	1
14 ln(Number of Employees)	0.133	-0.150	-0.183	-0.055	0.181	0.007	-0.107	-0.080	-0.046	0.428**	0.261*	0.309*	0.083

** Correlation is significant at the $p < 0.01$ level.
* Correlation is significant at the $p < 0.05$ level.

Table 4.4: Bivariate Correlations for UK Respondents
(two-tailed Spearman's ρ coefficient)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Relative Market Share	1												
2 Relative Average Profitability	0.565 **	1											
3 Relative Sales Growth	0.578 **	0.583 **	1										
4 Rel. Overall Financial Perf.	0.506 **	0.762 **	0.753 **	1									
5 Clockspeed	-0.188	-0.214	-0.329 *	-0.130	1								
6 New Suppliers	0.159	0.073	-0.134	-0.010	0.200	1							
7 Outsource	0.078	-0.071	-0.044	-0.148	-0.188	0.248	1						
8 Able to Learn	0.049	-0.006	-0.208	-0.148	0.050	0.491 **	0.422 **	1					
9 Values Relationships	0.281	0.153	0.217	0.219	-0.009	0.011	-0.081	0.267	1				
10 Costs Borne by Suppliers	0.190	0.219	0.270	0.175	0.137	0.036	-0.057	0.321 *	0.255	1			
11 Past Role	0.383 *	0.614 **	0.493 **	0.472 **	-0.446 **	-0.241	-0.015	0.011	0.173	0.128	1		
12 Future Role	0.464 **	0.432 **	0.279	0.392 **	-0.250	0.008	-0.057	0.088	0.349 *	-0.096	0.697 **	1	
13 Change in Strategy	0.344 *	0.112	0.103	-0.021	-0.100	-0.073	-0.125	-0.071	-0.088	0.167	-0.044	0.017	1
14 ln(Number of Employees)	0.435 **	0.160	0.134	0.174	0.342 *	0.396 **	0.216	0.333 *	0.155	0.164	-0.136	0.208	0.202

** Correlation is significant at the $p < 0.01$ level.
* Correlation is significant at the $p < 0.05$ level.

Table 4.5: Bivariate Correlations for International Respondents (two-tailed Spearman's ρ coefficient)

One particularly noteworthy outcome is that the "Number of Employees" variable is highly significant for two of the success indicators in the UK data set, and for one in the international sample. These results hint at the possibility that this control parameter may indeed play a significant role in the perceptions and behaviours of business units that are contending with radical innovations.

4.2.2 Hypothesis 2: Medium Clockspeed Firms Will Benefit More than Fast or Slow Ones

This hypothesis was also not meaningfully supported. Of the eight independent variables, only one of them, "Values Relationships," can be significantly correlated at the $p < 0.05$ level with the performance of a fast clockspeed business unit in the UK sample. A similarly weak degree of support is shown for medium clockspeed firms, which have two significant ($p < 0.05$) independent variables, and slow clockspeed firms, which have one.

The international data shows a similar pattern. Only three of the independent variables exhibit any kind of significant ($p < 0.05$) correlation to the dependent success indicators for fast clockspeed business units. The link is even weaker among medium clockspeed firms, however: only one independent variable, "Past Role," is significantly linked ($p < 0.05$) in this group.

		Fast Clockspeed (n = 28)		Medium Clockspeed (n = 27)		Slow Clockspeed (n = 12)	
Independent Variable and Hypothesized Relationship to Dependent Variables	Dependent Variables	Spearman ρ correlation	Spearman ρ significance	Spearman ρ correlation	Spearman ρ significance	Spearman ρ correlation	Spearman ρ significance
New Suppliers (+)	Relative Market Share	0.336	0.080 ◊	-0.240	0.228	-0.507	0.092 ◊
	Relative Average Prof.	0.118	0.551	-0.224	0.261	-0.100	0.758
	Relative Sales Growth	0.205	0.295	-0.276	0.164	0.089	0.784
	Relative Overall Fin. Perf.	0.112	0.572	-0.100	0.620	0.000	1.000
Outsource (+)	Relative Market Share	0.073	0.711	-0.111	0.581	0.153	0.634
	Relative Average Prof.	0.373	0.050 ◊	-0.329	0.094 ◊	0.261	0.413
	Relative Sales Growth	0.290	0.134	-0.363	0.063 ◊	0.539	0.071 ◊
	Relative Overall Fin. Perf.	0.146	0.459	-0.140	0.486	0.449	0.143
Able to Learn (+)	Relative Market Share	-0.009	0.964	-0.109	0.589	-0.605	0.037 *
	Relative Average Prof.	-0.033	0.867	-0.090	0.656	0.146	0.651
	Relative Sales Growth	0.064	0.747	-0.249	0.211	-0.120	0.710
	Relative Overall Fin. Perf.	-0.191	0.331	-0.167	0.405	0.113	0.727
Values Relationships (+)	Relative Market Share	0.290	0.134	0.227	0.255	-0.024	0.941
	Relative Average Prof.	0.623	0.000 **	-0.233	0.243	0.080	0.804
	Relative Sales Growth	0.592	0.001 **	-0.231	0.246	0.540	0.070 ◊
	Relative Overall Fin. Perf.	0.414	0.028 *	0.014	0.945	0.191	0.553
Costs Borne by Suppliers (+)	Relative Market Share	-0.250	0.199	-0.212	0.289	0.123	0.703
	Relative Average Prof.	-0.243	0.212	-0.342	0.081 ◊	0.288	0.364
	Relative Sales Growth	-0.170	0.387	-0.295	0.135	-0.172	0.593
	Relative Overall Fin. Perf.	-0.102	0.607	-0.235	0.237	0.151	0.640
Past Role (+)	Relative Market Share	-0.187	0.342	-0.279	0.158	0.365	0.243
	Relative Average Prof.	0.027	0.890	-0.475	0.012 *	0.162	0.615
	Relative Sales Growth	-0.180	0.358	-0.269	0.174	-0.375	0.230
	Relative Overall Fin. Perf.	-0.037	0.852	-0.341	0.082 ◊	0.000	1.000
Future Role (+)	Relative Market Share	-0.075	0.705	-0.266	0.181	-0.223	0.486
	Relative Average Prof.	0.230	0.239	-0.450	0.019 *	-0.176	0.585
	Relative Sales Growth	-0.122	0.538	-0.294	0.136	-0.483	0.111
	Relative Overall Fin. Perf.	0.088	0.655	-0.319	0.104	-0.341	0.278
Change in Strategy (-)	Relative Market Share	-0.080	0.687	-0.342	0.080 ◊	0.022	0.946
	Relative Average Prof.	0.199	0.309	0.009	0.964	-0.161	0.618
	Relative Sales Growth	-0.271	0.163	-0.122	0.546	0.382	0.221
	Relative Overall Fin. Perf.	0.064	0.747	0.083	0.681	-0.044	0.892
ln(Number of Employees)	Relative Market Share	0.528	0.007 **	-0.096	0.632	0.191	0.551
	Relative Average Prof.	0.034	0.872	-0.129	0.520	-0.297	0.348
	Relative Sales Growth	0.026	0.903	-0.251	0.207	-0.367	0.241
	Relative Overall Fin. Perf.	0.493	0.012 *	-0.174	0.385	-0.466	0.127

◊ Significant at the $p < 0.10$ level; * $p < 0.05$; ** $p < 0.01$

Table 4.6: Spearman ρ Coefficient and Significance for UK Respondents

		Fast Clockspeed (n = 30)		Medium Clockspeed (n = 12)	
Independent Variable and Hypothesized Relationship to Dependent Variables	Dependent Variables	Spearman ρ correlation	Spearman ρ significance	Spearman ρ correlation	Spearman ρ significance
New Suppliers (+)	Relative Market Share	0.109	0.580	0.283	0.373
	Relative Average Prof.	-0.051	0.787	0.331	0.294
	Relative Sales Growth	-0.178	0.346	0.414	0.181
	Relative Overall Fin. Perf.	-0.142	0.455	0.161	0.617
Outsource (+)	Relative Market Share	-0.092	0.642	0.291	0.358
	Relative Average Prof.	-0.145	0.444	-0.073	0.821
	Relative Sales Growth	-0.339	0.067 ◊	0.464	0.129
	Relative Overall Fin. Perf.	-0.324	0.080 ◊	0.054	0.867
Able to Learn (+)	Relative Market Share	0.022	0.913	0.067	0.836
	Relative Average Prof.	-0.152	0.424	0.146	0.650
	Relative Sales Growth	-0.362	0.050 ◊	0.439	0.153
	Relative Overall Fin. Perf.	-0.327	0.078 ◊	0.054	0.869
Values Relationships (+)	Relative Market Share	0.364	0.057 ◊	-0.375	0.229
	Relative Average Prof.	0.144	0.446	-0.271	0.394
	Relative Sales Growth	0.346	0.061 ◊	-0.122	0.707
	Relative Overall Fin. Perf.	0.328	0.077 ◊	-0.569	0.053 ◊
Costs Borne by Suppliers (+)	Relative Market Share	0.283	0.145	-0.147	0.648
	Relative Average Prof.	0.331	0.074 ◊	0.012	0.970
	Relative Sales Growth	0.373	0.043 *	0.276	0.386
	Relative Overall Fin. Perf.	0.355	0.054 ◊	-0.342	0.277
Past Role (+)	Relative Market Share	0.182	0.353	0.344	0.274
	Relative Average Prof.	0.581	0.001 **	0.013	0.967
	Relative Sales Growth	0.284	0.129	0.674	0.016 *
	Relative Overall Fin. Perf.	0.368	0.046 *	0.263	0.409
Future Role (+)	Relative Market Share	0.393	0.039 *	0.307	0.332
	Relative Average Prof.	0.337	0.069 ◊	0.251	0.432
	Relative Sales Growth	0.264	0.159	0.023	0.943
	Relative Overall Fin. Perf.	0.280	0.134	0.525	0.080 ◊
Change in Strategy (-)	Relative Market Share	0.290	0.135	0.357	0.255
	Relative Average Prof.	0.029	0.878	0.105	0.744
	Relative Sales Growth	0.039	0.837	-0.002	0.995
	Relative Overall Fin. Perf.	-0.219	0.244	0.422	0.172
ln(Number of Employees)	Relative Market Share	0.604	0.001 **	0.317	0.315
	Relative Average Prof.	0.275	0.142	-0.159	0.622
	Relative Sales Growth	0.253	0.177	-0.065	0.840
	Relative Overall Fin. Perf.	0.143	0.451	0.104	0.747

◊ Significant at the $p < 0.10$ level; * $p < 0.05$; ** $p < 0.01$

Table 4.7: Spearman ρ Coefficient and Significance for International Respondents

4.3 Chapter Summary

This chapter began with an explanation of how the raw survey responses were interpreted and framed prior to further examination, and then reviewed the univariate and intercorrelation characteristics of the data. Next, it discussed the various statistical tools that were considered for analyzing the data, and explained why Spearman's ρ was eventually chosen. Then it concluded by directly determining whether or not the data supported the two hypotheses put forward earlier in the thesis. The three chapters following this one will present case studies in an attempt to explain the results of the survey data. To this end, the next chapter will focus on the Intel Corporation, a fast clockspeed organization, and the transition to organic/C4 packaging in the company's microprocessors.

CHAPTER 5: FAST CLOCKSPEED CASE STUDY—INTEL'S TRANSITION TO ORGANIC/C4 PACKAGING

This case study has three principal objectives. First, it will establish that the Intel Corporation's packaging business unit is indeed a fast clockspeed organization. Second, it will document the circumstances underlying the make-buy decisions behind Intel's transition from ceramic/wire bonded microprocessor packaging to organic/C4 packaging, and shed light on the motives and circumstances that led to the company's outsourcing decisions throughout this transition. Third, this study will cast light on the relationships between Intel and its suppliers during the move from ceramic/wire bonded packaging to organic/C4 units.

5.1 Establishing Intel's Packaging Business Unit as a Fast Clockspeed Organization

Fine (1998, p. 239) specifically points to semiconductor manufacturing as a fast clockspeed industry. And to be sure, interviews with managers and engineers throughout Intel strongly support the estimates that Fine uses to arrive at this categorization: new product technologies are introduced every 1-2 years, process technologies change every 3-10 years, and the company undergoes a period of major organizational restructuring every 2-3 years. The technical realities of microprocessor design leave little doubt that this classification also applies to Intel's packaging business unit. A microprocessor's packaging must change and evolve to keep up with the silicon chips that they are attached to, and the company's packaging group, which consists of 150-200 people distributed over various locations around the world, is therefore most definitely a fast clockspeed organization in its own right.

5.2 Company Description and Industrial Context

Credited with creating the world's first microprocessor in 1971, Intel figures prominently in the semiconductor industry. The company currently has nearly 78,000 employees in several countries, generates annual revenues of $26.7 billion,[24] and is the seventh largest company in the world in terms of market value (Wall Street Journal Europe, 2003).

This uncommon size and success has brought about a rather unique dynamic that significantly influences how Intel deals with its suppliers, and how the company reacts to its competitors. One senior director summed up the situation by describing the microprocessor sector as "very unbalanced." Nearly 80 percent of the microprocessors used in computers around the world come from Intel; the other 20 percent come from much smaller rivals such as Advanced Micro Devices (AMD), Motorola, and the Taiwan Semiconductor Manufacturing Company (TSMC). Most of Intel's competitors offer alternative products that are comparable in many regards to Intel's own, but there are some major hurdles that prevent them from becoming a major threat to Intel's dominant position in the foreseeable future.

One particularly tall hurdle is that the semiconductor sector is extremely capital-intensive. Intel's managers are quite forthcoming about the fact that companies like AMD and Motorola are able to arrive at microprocessor designs that are both innovative and technically impressive. But all of Intel's competitors face considerable difficulty when it comes to high volume manufacturing and quickly delivering their innovations to the market. Today's fabrication facilities for semiconductors can each cost on the order of $3 billion (Tristram, 2003). This amount represents approximately one-tenth of Intel's annual revenue stream—but according to one Intel manager, it is nearly equal to the total annual earnings of AMD. Intel's massive size and deep pockets provide a natural and rather daunting obstacle that its competitors find very difficult to overcome. A senior Intel supervisor summed up the future prospects of these smaller companies by saying "I'm just not able to see how they'll catch up."

[24] This was the company's earnings in 2002. Source: http://www.intel.com/intel/index.htm (4 September 2003).

5.3 The Role of Packaging in Microprocessors

The traditional role of microprocessor packaging was merely to provide an interface between the microprocessor's microscopic silicon-level interconnections and the much larger motherboard while providing protection for the chip from the external environment (Mahajan, Brown, & Atluri, 2000, p. 1). As microprocessor performance has advanced, however, packaging has evolved to take on a decidedly more sophisticated role. Because today's semiconductors consume considerably more electrical power than in the past, modern packaging designs, an example of which is shown in Figure 5.1, now include complex power delivery systems and contain many more features for heat dissipation than was required even ten years ago. And this rate of change is not expected to slow down anytime soon. Propelled by Moore's Law[25] and the breakneck pace of developments in silicon chip engineering, packaging is becoming an increasingly important area in the field of microprocessor design and manufacturing.

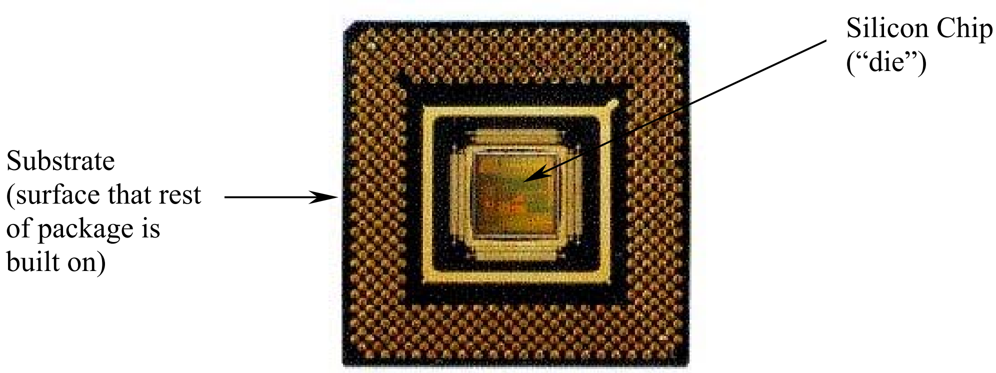


Figure 5.1: A Silicon Chip Mounted in a Typical Packaging Unit [26]

The range of tasks and responsibilities managed by Intel's packaging business unit is quite broad. As illustrated in Figure 5.2, the process begins by using a wafer saw to cut larger, round silicon wafers into individual chips. Then the chips, which are commonly referred to in the industry as "dies," are physically connected to the packaging substrate in the "die attach" process and secured in place. The chip is then electrically connected to the rest of the computer and hermetically

[25] Established in 1965 by Gordon Moore of Intel, Moore's Law originally stated that microprocessors tended to double in power and transistor density about every two years (an exponential growth rate). The timeframe for this doubling has since been shortened to 18 months.

[26] Source: http://aml2.eng.rpi.edu/GMPWeb/SProjectsPwrpt/spring2003/Electronics.ppt (17 September 2003).

sealed inside the packaging with a ceramic lid to protect it from any kind of impact or foreign material. After being fused together, the chip and packaging are then subjected to a series of inspections known as "electrical testing and burn-in." Designed to weed out particularly sensitive units, this stage entails subjecting the chip and packaging to voltages and temperatures that are appreciably higher than what would be expected in a normal operating environment. Finally, the finished product is marked with a unique serial number and product specification code before being sent on to other parts of the company for distribution.

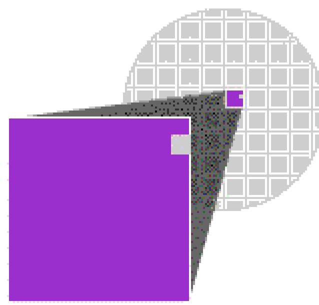


Figure 5.2: Silicon Chips Cut from Wafers by Sawing [27]

The introduction of the Pentium II generation of microprocessors brought about radical changes in two major aspects of the above process: (1) the substrate material and (2) the method for electrically connecting the chip to the packaging. Prior to the Pentium II, Intel's packaging units were built on ceramic substrates, and silicon chips were electrically connected to the surrounding packaging by a method called "wire bonding"; after the jump, the substrates were made from "organic" composite materials, and were connected by a technique known as "C4." The change required considerable effort and resources from Intel's packaging business unit, and had a noticeable impact on its supply network.

[27] Source: http://www.intel.com/education/makingchips/fabrication.htm (10 September 2003).

5.4 The Old Technology: Ceramic/Wire Bonded Packaging

5.4.1 The Technology

Ceramics are essentially a class of inorganic and non-metallic materials that includes substances like carbides (SiC), pure oxides (Al_2O_3), and nitrides (Si_3N_4). The relative insensitivity of ceramics to heat and their near-zero electrical conductivity made them an attractive choice as a substrate material for early generations of packaging. Based on the process described in the previous section, Figure 5.3 outlines the basic steps for connecting a die to a ceramic packaging unit. The old packaging technology consisted of applying a silver-filled epoxy to the chip and connecting it to the substrate in the "die attach" process. While the die attach process physically connected the chip to the packaging, however, it did not electrically connect the chip to the rest of the computer. This was the job of the wire bonding process.

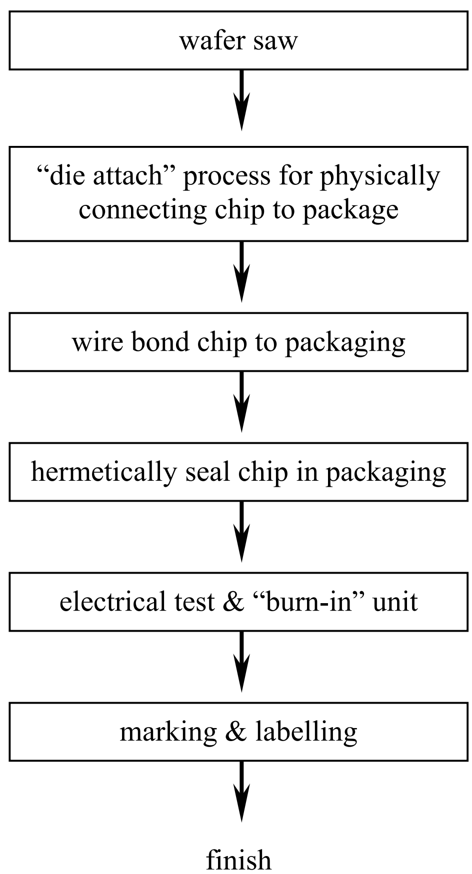


Figure 5.3: Manufacturing Procedure for Ceramic/Wire Bonding Packaging

As shown in Figure 5.4, wire bonding essentially consists of connecting extremely fine gold or aluminum wires between pads on the chip and corresponding pads on the surrounding packaging. Wire bonding machines are designed very specifically for this task, and Intel has thousands of them around the world. A single building in the company's fabrication facilities can contain as many as 100 of these machines. Wire bond technology and equipment are very mature by industry standards, and this process can therefore be accomplished with defect rates very close to zero.

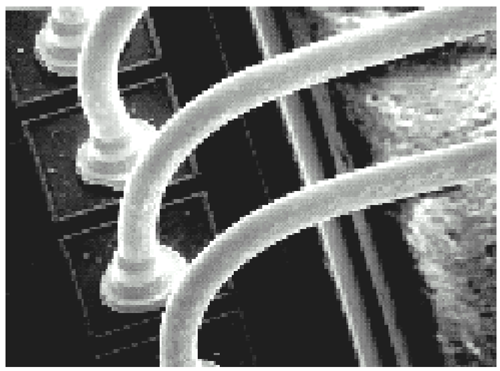


Figure 5.4: Scanning Electron Micrograph of Wire Bond Between Die and Packaging [28]

5.4.2 Outsourcing Strategy

Ceramic/wire bonded packaging units were delivered to Intel as nearly finished components by three suppliers: Kobe Semiconductor, Shinto Electronics, and Nurimoto Packaging.[29] Intel had been purchasing packaging from all three companies for many years. "Supplier re-use" is an important part of Intel's strategy, and the company goes through considerable lengths to make sure that it can preserve relationships with its key suppliers for as long as reasonably possible. At the root of this policy is the fact that Intel has to expend a lot of manpower and money to establish and develop a productive relationship with a new supplier. The company has a reputation in the industry for having uncommonly high standards and for expecting firms in its supply network to adopt very precisely defined norms of conduct. One senior manager in Intel

[28] Source: http://www.dieproduct.com/Tutorials/hand_ship/Wire_Bond/wire_bond.html (9 September 2003).

[29] These are not the real names of the companies. The Intel Corporation maintains a strict policy of not publicly disclosing its suppliers, and aliases are accordingly used in this thesis to identify them.

estimated that it takes between two and five years to "Intel-ize" a new supplier—that is, to teach them about Intel's standards, protocols, and ways of doing business.

Remaining true to Intel's overarching principle of maintaining supplier relationships, the company's packaging unit has worked with its supply base to foster what they refer to as an "open kimono" culture in which detailed information can be openly shared between the packaging unit and each of its principal suppliers. The unit's managers work closely with each of its top-tier suppliers to develop highly detailed cost models and a deeply rooted understanding of the technical details of their operations so that Intel can work with the suppliers to reduce their overall costs and improve quality. But this approach is, according to several managers in the packaging business unit, not a typical one in the industry. Competitors such as Motorola and AMD usually just ask to see samples and prototypes from their suppliers, and are much less concerned about—or simply may not have the resources to focus on—the specific operational details and cost information behind the units that they buy.

The flow of information between Intel and its supply base is not one-way, however. Intel hosts an annual "Supplier Day" during which the company reveals its long-term plans and intentions to its principal collaborators and suppliers. "We basically use it as an opportunity to let them know what we're going to need and why we're going to need it. We want to get the suppliers working together so that we can move things forward," said one manager.

Despite the obvious economies of scale that might have been achieved by purchasing all of its ceramic/wire bonded packaging from a single source, however, Intel preferred to buy them from the three Japanese firms—that is, Kobe, Shinto, and Nurimoto. There were four principal reasons behind this decision. First, as discussed earlier, the semiconductor industry is quite capital-intensive compared to other sectors, and the Intel team reasoned that any one supplier would almost certainly face considerable difficulty in trying to build enough production capacity to accommodate Intel's requirements. Intel usually expects its suppliers to absorb most of the costs associated with acquiring new technologies and equipment. "This is just their part of taking risks in the industry," said one Intel manager. Spreading this risk among three companies seemed like a more realistic solution than asking a single firm to bear the investment alone.

The second reason for outsourcing the production of the packaging to three firms is that, by purchasing from multiple firms, Intel considers itself less exposed to the naturally arising uncertainties of the marketplace. Companies enter and exit the semiconductor business on a fairly regular basis, and Intel usually prefers using multiple sources for a particular input as a means for minimizing the likelihood that it will be left without any supply at all. One supplier may fail, but it is extremely unlikely that all three of them would falter simultaneously, thereby protecting the expertise and accumulated know-how in the supply base. In this spirit of supply chain robustness, Intel also typically prefers not to make any one supplier too dependent on Intel's business. The company's managers usually do not to let more than 30 percent or so of a supplier's revenue come from Intel.

Third, Intel's management team uses its multiple source strategy as a very effective mechanism for motivating its supply base. If one firm begins to fall behind the others in delivering a particular component or input, Intel can use one supplier's best practices as a guideline for helping the other, less competitive suppliers to improve.

Fourth, despite Intel's size and impressive array of in-house R&D activities, many of the company's managers believe that they can benefit from exposure to talented people and inventive ideas that pop up in organizations outside their own. Procuring components and services from multiple suppliers allows Intel to keep in touch with outside developments, and maintaining links with more suppliers almost surely makes it possible to talk to more people and get exposed to more new ideas.

Despite the company's clear preference for procuring its components from multiple suppliers, however, Intel works very hard to ensure that there is very little variation in the actual processes and methods used by each supplier. A cornerstone of Intel's overarching strategy is its "Copy Exactly!" philosophy. When the Intel team finally converges on a successful design or process for a specific product line, the company and its suppliers quickly ramp-up production by making exact clones of the finalized manufacturing environment and faithfully duplicating the original inputs. No variables are changed or adapted whatsoever from one plant to the next. Behind this approach is the belief that any manufacturing process is subject to an overwhelming number of influencing effects. Rather than trying to rationalize all of the complexities of a manufacturing system and model the thousands of variables involved, Intel prefers merely to reproduce a working formula without necessarily understanding exactly why it is successful. Using this strategy, the company has been able to ramp-up production for new generations of microprocessors in less than half the time of its competitors. Intel's managers are therefore quite adamant that the company's suppliers should also adopt the "Copy Exactly!" policy, which entails closely following the precise specifications handed to them by Intel. Attempts by the suppliers to improvise on their own without Intel's explicit approval are quite unwelcome.

5.5 The New Technology: Organic/C4 Packaging

5.5.1 The Technology

Ceramic/wire bonded packaging served Intel quite well for many years, but advances in the speed of microprocessor designs were beginning to make wire bonding technology a somewhat cumbersome option. Intel's engineers realized that the natural inductance of the wires connecting the chip to the packaging would hinder the performance of Intel's microprocessor designs as chips in excess of 200 MHz were introduced. The company's managers and engineers accordingly decided in 1996 to stop using wire bond designs and to replace them with "C4" connections, a new technology that made its Intel debut in the Pentium II generation of microprocessors.

Controlled collapse chip connecting (C4), or "flip chip" as it is sometimes called, offered a significant improvement over wire bonding with regards to the electrical characteristics of the chip-packaging interface. Developed by IBM in the 1960s for ceramic substrate packaging, C4 connections resulted in considerably less inductance than wire bonds, thereby causing less overall impedance in the connections. The C4 approach also offered a 30-40 percent reduction in the surface area of the packaging compared to wire bonding, which consequently helped the company's technical design teams in their constant drive towards miniaturization.

Instead of connecting pads on the chip and packaging with very thin wires, C4 technology makes this connection via matching sets of electrically conducting balls that are configured in an array on both the silicon chip and the packaging as shown in Figure 5.5. Flux is applied to the surfaces of both sets of connecting balls to remove any oxidation that might prevent a solid electrical connection. The packaging substrate and die are then heated to 240 ºC in a furnace, and the die is lowered face-down on to the packaging such that the connecting balls on the chip and packaging gently touch each other. When two sets of connecting balls come together, as shown in Figure 5.6, they form a grid of connections that solidifies when the packaging and die are cooled.

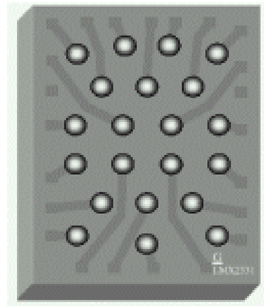


Figure 5.5: Control Collapse Chip Connect (C4) Ball Array [30]

To protect the relatively fragile C4 connections, an "underfill" is put into the extremely small spaces between the connections. Specifically, the role of underfill is to enhance the thermal and mechanical vibration fatigue reliability of the joints, as well as to offer the connections some measure of resistance to impact or physical shocks. Capillary flow is the mechanism by which underfill moves through the joints, and the process therefore requires considerable knowledge and experience with the materials used in this process. The viscosity and adhesive properties of the material are extremely important during the fluid phase, while the material's thermal expansion and mechanical strength characteristics are very important once the medium has solidified.

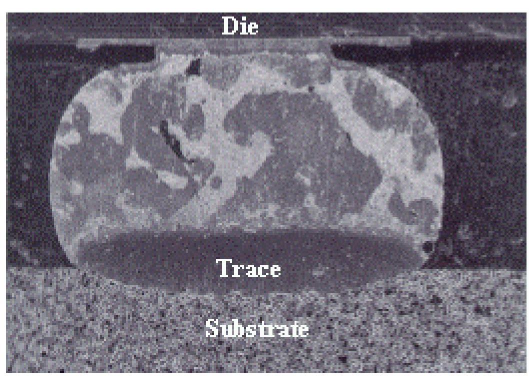


Figure 5.6: C4 Connection between Packaging and Die [31]

[30] Source: http://www.dieproduct.com/Tutorials/hand_ship/Flip_Chip/flip_chip.html (9 Sept 2003). Note that this illustration is not drawn to scale, and is offered only to communicate the basic idea of C4 technology. The individual connecting balls are actually so small that they are very difficult to see.

[31] Source: http://www.dieproduct.com/Tutorials/hand_ship/Flip_Chip/flip_chip.html (9 Sept 2003).

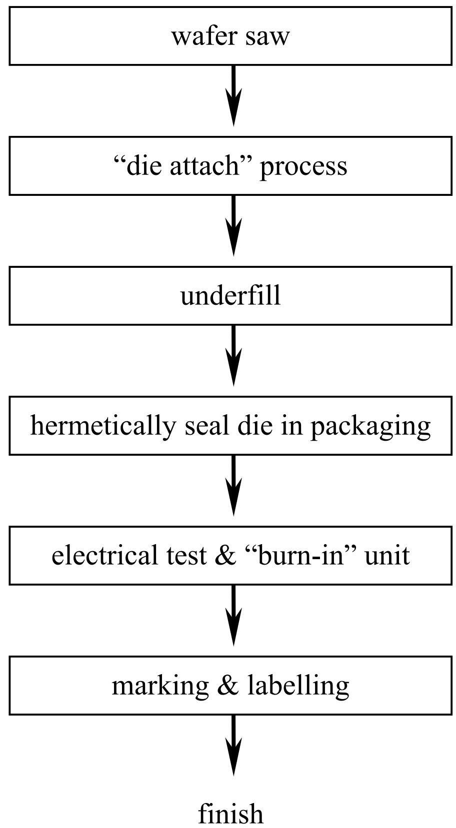


Figure 5.7: Manufacturing Procedure for Organic/C4 Packaging

As shown in Figure 5.7, the organic/C4 process then begins to look more or less exactly like the ceramic/wire bonding process: a lid is attached to hermetically seal the chip and protect it from damage, and the finished microprocessor is tested and marked before being sent onward to other parts of the company for distribution.

In addition to the transition from wire bonding to C4 connections, Intel also chose the Pentium II generation of microprocessor for making the jump from ceramic substrate packaging units to "organic" ones. Organic packaging basically consists of a fibreglass matrix that is impregnated with an epoxy resin and hardened. The decision to make this change was largely motivated by economics: ceramic packaging typically costs around $20/unit, while the price of an organic unit can, after an initial learning period, cost as little as $3. Organic packaging technology also offers a higher degree of precision and tolerance control than ceramics. And the new approach resulted in a significant reduction in the dielectric properties of the packaging material, thereby lessening the amount of undesirable electrical interference that the packaging would create for the silicon chip while the microprocessor was in operation.

It is important to note, however, that Intel's engineers are quite forthcoming about the fact that neither the move from ceramic to organic packaging nor the transition from wire bonding to C4 was particularly challenging when considered separately. Both of these jumps had been accomplished previously in other companies, and the processes for each were reasonably well documented. What made these technology jumps considerably more dramatic in this particular case was the fact that they occurred *together*. Because the C4 connection process entailed exposing the packaging and the chip to very high temperatures and then letting them cool, the coefficient of thermal expansion (CTE) for each component was a key consideration. But silicon chips and organic substrates have markedly different CTEs, and it was therefore not known at the outset of the project whether the C4 connections would shear as the microprocessor was cooling during the packaging operations. It was therefore decided by Intel's senior managers that, to achieve this goal in time for the Pentium II generation, the company would have to work closely with its suppliers.

5.5.2 Outsourcing Strategy

Before the decision to move towards organic packaging with C4 connections, Imoko Composites[32] of Japan had very little prior exposure to Intel's packaging business unit. But with nearly 20 patents in the field, the company's highly specialized experience with high-precision epoxy and fibreglass molding made it an attractive partner for this undertaking, and the Intel team decided to bring Imoko on board as a supplier for the new packaging technology.

As was usually done for R&D work with its packaging suppliers, the Intel managers began with the assumption that Imoko should play the principal role in developing and perfecting this technology, and that Imoko would bear most of the costs for this. But it quickly became clear to Intel that Imoko was experiencing considerable difficulty in making this happen. While Imoko had made impressive advances in developing C4 arrays on organic substrates over the ten-year period prior to partnering with Intel, there were still some rather troublesome problems with their process that clearly needed to be solved. Engineers and managers from the two companies

[32] As for the other suppliers discussed in the Intel case study, this is not the company's real name.

examined the technology together and diagnosed that the problems could probably be overcome—but it would take an additional investment of $250 million to achieve these goals in time for the Pentium II.

The total capital value of Imoko at the time was estimated by Intel to be on the order of $750 million, so an investment of $250 million clearly represented a nearly insurmountable obstacle for a company of Imoko's size. But the Intel team realized, too, that the transition to the organic/C4 packaging was on the critical path for the Pentium II generation microprocessor. Design teams working on other parts of the microprocessor such as the silicon chip were already basing their designs on the assumption that the organic/C4 transition would be successful. Intel therefore decided towards the end of 1996 to step in and help Imoko with a large investment to accelerate the development process. As well, a group consisting of between seven and twelve engineers from Intel's US fabrication plants was assigned to work with Imoko's R&D team on a full-time basis in Japan.[33] The size of the team varied according to the specific requirements of the project: extra manpower was temporarily assigned to troubleshoot problem areas as required. Throughout the first ten months of 1997, Intel personnel worked on a regular and repeating cycle consisting of two to three weeks of living and working in Japan, followed by a one-week trip home to the US before returning to Japan again. This rather intense schedule did pay off, however. As 1997 drew to a close, the Intel and Imoko engineers announced that they had successfully overcome the production problems, and that the organic/C4 technology was officially ready for ramping up to full production.

Remaining true to its longstanding policy of using multiple suppliers, Intel then worked directly with Imoko to license the organic/C4 technology to two other companies: Shinto Electronics and Nurimoto Packaging, both of which had been suppliers of ceramic/wire bonded packaging to Intel for many years. In the interest of saving travelling time and money, Intel did consider licensing the technology to a handful of US-based packaging manufacturers. After a careful analysis of these firms, however, Intel's managers decided in favour of the Japanese packaging suppliers

[33] Directly intervening in the progress of its suppliers was not an entirely new strategy for Intel. In their analysis of Intel's move to the PCI bus architecture for the first Pentium processors, Gawer & Cusumano (2002) capture one Intel manager's rationalization of the company's outsourcing strategy: "Why did we enter the chip set business? We got into the chip set business in a major way *to accelerate platform transitions*. To unleash the power of the Pentium, we had to introduce the new PCI bus. We did start by giving specifications [to the chip set manufacturers]. We started with traditional enabling, which is you give specs out, you evangelize that the processor is going to need it, you make the technical case, you make a marketing case, and you say that you're going to advertise it to make it important to the industry. But we realized that wasn't good enough because they weren't fast enough. One of the most troublesome things was that it was really hard getting the other chip set vendors to do PCI right" (pp. 87-88).

because of their significantly larger commitment to R&D for the new technology. The US companies that Intel approached were either financially unable to invest such a large sum of money or were simply too risk-averse to pursue this new direction with Intel, so the company was forced to look further afield for potential collaborators.

While Shinto Electronics and Nurimoto Packaging had considerable experience in microprocessor packaging, however, they were not yet proficient with every aspect of the technologies directly related to the new organic/C4 design. Nurimoto had some experience with the processes involved but, because Imoko's version of the technology had been adopted by Intel first and identified as a "Copy Exactly!" technology, Nurimoto had to pay for a licensing agreement so that they could use exactly the same materials as Imoko. Shinto also had to adopt Imoko's technology in order to adhere to Intel's "Copy Exactly!" principle, but Shinto had even less experience in the field than Nurimoto, and therefore required significantly more direct assistance throughout the transition to the new technology. Shinto's managers accordingly agreed to a licensing agreement with Imoko that encompassed both the process technologies and the required materials.

With the new licensing arrangements came a shift in Intel's manpower allocation strategy for the project. Because things were winding down in the R&D phase, a few members from Intel's team of seven engineers at the Imoko facility were re-deployed to the Nurimoto and Shinto sites to aid in the technology transfer processes in those companies. The Intel engineers worked with both suppliers for several months until they were able to produce packaging units that were virtually indistinguishable from Imoko's.

But at the same time, there were other, larger forces at work that were significantly hindering Shinto's efforts to adopt the new technology. The widespread economic malaise throughout the Japanese economy during this period had a dramatic effect on Shinto's bottom line. Nurimoto was nearly eight times as big as Shinto in terms of market capitalization, and was therefore in a better financial situation to withstand the downturn. Moreover, a significant fraction of Nurimoto's income came from the automotive industry, which tends to offer more robust demand schedules for its suppliers than the highly volatile microprocessor industry. Shinto, by stark contrast, did not have any contracts with the automotive suppliers that could help it through this difficult period. Shinto did indeed manage to become certified to supply organic/C4 packaging units to Intel, but Intel's managers had strong doubts about the supplier's ability to do so in the future. Intel consequently reversed its original verdict and decided not to use Shinto as a supplier of organic/C4 packaging units. However, to soften the blow for Shinto, Intel's managers encouraged Imoko to purchase a significant fraction of Shinto's organic/C4 production facility.

Perhaps just as notable as who did join Intel in its transition to organic/C4 packaging is who did not. As noted earlier, Kobe Semiconductor had also been a very large supplier of packaging to Intel for decades prior to this transition—"practically forever in this industry," as one manager pointed out—but the company preferred not to invest in the new organic/C4 technology. In spite of the fact that hundreds of millions of dollars of Kobe's revenue stream came from Intel, Kobe's managers fundamentally disagreed with Intel about where the microprocessor sector was headed with respect to packaging technologies. Kobe also had several other customers for its ceramic packaging, and these other firms had indicated that they were not particularly interested in moving towards organic/C4 packaging at the time. With billions of dollars in annual sales built almost entirely on a core competence of ceramic products, Kobe had a broad range of customers in many industries around the world. The firm's managers therefore quite naturally considered Kobe to be a ceramics company first and foremost. To accommodate Intel's request to move to organic/C4 packaging would take the company's focus away from this fundamental principle.

The managers within Intel's packaging business unit were not happy at the thought of severing their relationship with Kobe. Its above-average size in the industry and the longstanding relationship that it shared with Intel made it a valuable partner, and managers within the two companies had developed a tremendous amount of trust and rapport. Towards preserving the relationship, Intel even went so far as offering to hand over the new technology to Kobe and to train the supplier's engineers to become proficient with it. But in the end, Kobe did not agree with Intel's new direction in the market, and politely declined the offer.

5.6 Why This Was a Radical Innovation

The transition from ceramic/wire bonded packaging to organic/C4 represented a significant shift in the equipment and skill sets required by both Intel and its suppliers. Ceramic/wire bonded packaging involves thousands of highly specialized wire bonding machines that cannot be easily reconfigured to perform any other useful task. Organic/C4 packaging needs none of these machines, but instead requires furnaces for heating the connecting balls. Producing organic/C4 packaging units only requires one-third of the man-hours of ceramic/wire bonding.

The move from ceramic/wire bonding to organic/C4 quite predictably led to the end of the longstanding relationship between Intel's packaging business unit and the US-based supplier from which Intel used to buy its wire bonding equipment. The existing supplier's technologies were so different from what was required for the organic/C4 packaging that the supplier could not establish any kind of role for itself with the new technology.

5.7 Chapter Summary

This chapter documented the circumstances underlying the make-buy decisions behind Intel's transition from ceramic/wire bonded microprocessor packaging to organic/C4 packaging, and shed light on the motives and circumstances that led to the company's outsourcing decisions throughout this transition. Finally, it discussed the relationships between Intel and its suppliers during the move from ceramic/wire bonded packaging to organic/C4 units. To contrast Intel's experiences with those of medium clockspeed firms, the next chapter will discuss Domino Printing Sciences' expansion into the laser printing market.

CHAPTER 6: MEDIUM CLOCKSPEED CASE STUDY—DOMINO PRINTING SCIENCES' MOVE TO LASER PRINTING

First, this case study will establish Domino Printing Sciences as a medium clockspeed business unit. Second, it will discuss the circumstances underlying the make-buy decisions behind Domino Printing Science's transition from inkjet printing to laser printing, and shed light on the motives and circumstances that led to the company's outsourcing decisions throughout this technological step-change. Third, this study will examine the relationships between Domino and its principal suppliers during the shift to laser printing.

6.1 Establishing Domino as a Medium Clockspeed Organization

According to Domino's Technical Director,[34] the company introduces new product technologies every five years, which comfortably falls within the 4-10 years window that Fine (1998) offers as a defining characteristic for medium clockspeed industries such as bicycle manufacturing or the automotive sector. He also estimates that the company changes organizational structures every four years and introduces significant new process technologies every five years. Both of these rates of change also fall within the definitions put forward by Fine (1998, p. 239) for characterizing medium clockspeed industries. Thus, based on these criteria, Domino can be regarded as a medium clockspeed business unit.

[34] Dr. Rick Mitchell, Group Technical Director of Domino Printing Sciences. Personal communication with author, 3 July 2003. Dr. Mitchell has since retired from the company.

6.2 Company Description and Industrial Context

Founded in 1978, Domino Printing Sciences is a manufacturer and distributor of industrial inkjet and laser printing systems. The company has grown from its early days as a R&D facility to become a large multinational company that employs over 1,700 people and generates an annual revenue stream of over $200 million. Based in Cambridge, England, Domino's products are sold in over 120 countries via a network of 16 subsidiary offices, but the manufacturing and R&D aspects of the business are confined to the UK, US, and Asia.

The company develops and manufactures marking and printing systems for industrial applications. The type of printing that Domino focuses on is based on competencies and skills that are significantly different from those used in the types of printers traditionally found in homes and offices. Domestic and office printing typically involves depositing ink or making a mark with a laser on flat paper at very close distances and under well controlled circumstances. By stark contrast, Domino develops systems that apply ink or aim lasers under much less straightforward conditions, such as uneven, metallic, or slick surfaces that are passing by the printer at high speeds. Consequently, in spite of the fact that companies like Hewlett-Packard and Canon have a tremendous amount of in-house knowledge about desktop printing, it is quite unlikely that these firms would attempt to cross over into Domino's market, or vice-versa.

Domino is the second largest firm in the industrial printing sector, currently controlling approximately 25 per cent of the market's $1 billion per year revenue stream.[35] The company is slightly smaller than Videojet, a US-based rival, but is larger than other major players in the industry such as Linx from the UK, Imaje from France, and Willett in the UK. Both Domino and its competitors develop and make capital equipment that is installed in other firms' manufacturing operations. Domino also generates a significant part of its revenue by selling the specialty inks that are used in its inkjet units.

Among Domino's bigger clients is the carton printing and labelling sector, with annual sales of about $80 billion. The sheer size and momentum of this market represents a barrier for new technologies inasmuch as the adoption of an innovation by the industry would involve many firms and cost a considerable amount of money.

[35] Source: a roundtable discussion involving the author and several of Domino's director-level managers on 18 April 2002.

6.3 The Role of Industrial Printing

From the barcodes used for tracking courier packages to the customized printing that indicates a subscriber's name and address on the cover of a magazine, industrial printing has been used for many years on a broad range of everyday products in the marketplace. As shown in Figure 6.1, these technologies are also used to create the ubiquitous "best before" stamps that appear on food packages.

Figure 6.1: Product Marking on a Drink Bottle[36]

Domino provides a broad range of equipment and services to accommodate the needs of its customers. In addition to the hardware required for marking and printing, the company also offers a variety of consumables such as inks, filters, and cleaning fluids. And to ensure that its customers can maximize the uptime of their printing equipment, Domino also offers a range of training packages and onsite service contracts.

The company successfully met its customers needs for many years with inkjet printers, but this technology was increasingly frowned upon by some of Domino's clients because of its dependence on solvents. As Domino's customers became more and more sensitive to

[36] This is a modified version of an image taken from Domino's web site: http://www.domino-printing.com (21 July 2003).

environmental issues and the health of their workers, the company's directors began to look for alternative printing technologies that minimized or eliminated the need for potentially hazardous chemicals. Laser printing offered an attractive solution to this growing concern, and Domino's managers regard the new technology as an important growth opportunity. Laser printing systems currently account for only 15 per cent of Domino's revenues, but the company expects this figure to grow steadily as existing inkjet customers gradually become more comfortable with laser printing. However, the change from inkjet printing to laser technology has required a considerable amount of effort and resources from Domino, and the shift is leading to major changes within the company's supply network.

6.4 The Old Technology: Continuous Inkjet Printing

6.4.1 The Technology

At the heart of Domino's inkjet printing system is a mechanism for imparting an electrostatic charge to ink droplets. As shown in Figure 6.2, ink is forced under pressure through the drop generator, and emerges through a small nozzle as a fine jet. The drop generator contains a drive rod that creates ultrasonic pressure waves in the ink, which in turn cause the jet to break up into a stream of very small individual droplets as the ink leaves the nozzle. Each droplet is electrostatically charged by applying a voltage to the charge electrode as droplets continuously break away from the jet. The size of the charge on an ink droplet depends on the voltage applied to the charged electrode at the moment the droplet passes by.

The ink drops then pass through an electrostatic field that is created by two high voltage deflector plates. The trajectory of each charged ink drop is determined by the size of the charge on the particular drop: a larger induced charge results in a sharper angle of deflection. The droplets land in a column on the surface of the object being printed. The printing surface then moves slightly with respect to the stationary print head, and another column is printed. This process of printing a column and shuffling slightly sideways continues over and over again until the desired two-dimensional image is formed. Ink drops not required for printing are not given an electrostatic charge, and are recycled via the gutter.

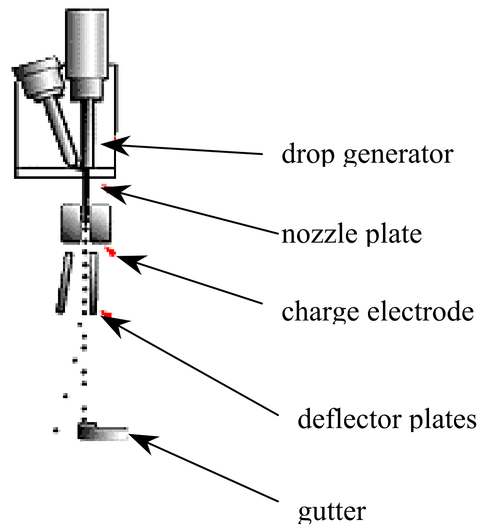


Figure 6.2: Domino's Inkjet Printing Technology [37]

The resolution of the printed characters is a function of the size of droplets being generated, which is in turn dependent on the size of the hole in the nozzle. The nozzle sizes used in Domino printing units range from 40-75 μm, resulting in printing speeds of up to 2,000 characters per second.

The intrinsic properties of the inks themselves play a critical role in the printing technology. Highly specialized inks were engineered by Domino that could accumulate electrical charges relatively well, and that have both a very particular viscosity and surface tension so that the inks will coalesce into droplets of the right size inside the drop generator. To achieve these ends, Domino's engineers had to use volatile chemicals in the inks so that the droplets could dry relatively quickly on non-absorbent surfaces such as metal containers.

As shown in Figure 6.3, the process of manufacturing a Domino inkjet printing system begins with a study of the customer's situation to determine which of the 12 available printing systems would best suit their requirements. Each inkjet unit consists of four modular subsystems: the ink system, a nozzle, electronic subsystems, and a user interface. The modules are assembled in a cabinet and installed at the customer's manufacturing site.

[37] Source: http://www.domino-printing.com/technology/inkjetprint.html (21 July 2003).

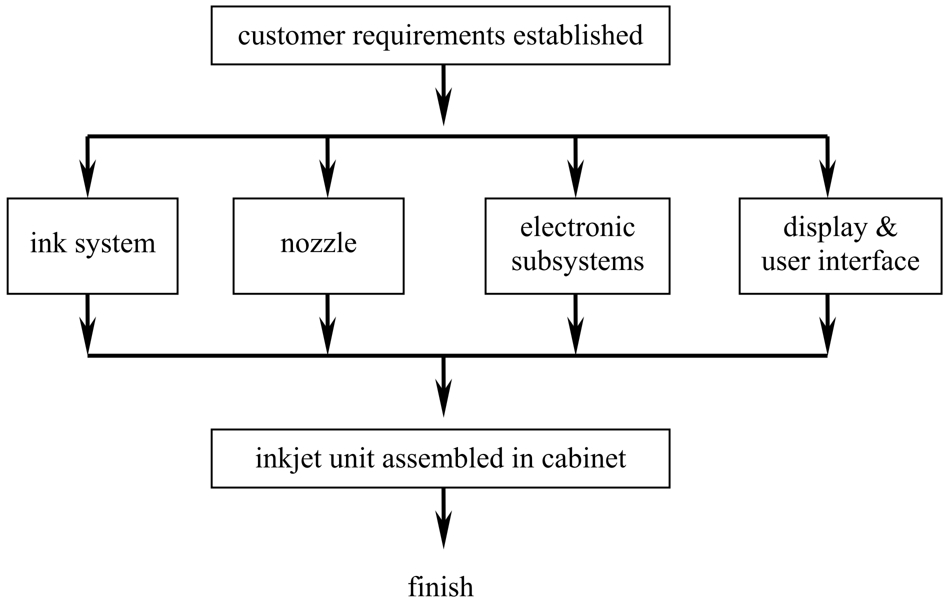


Figure 6.3: Manufacturing Procedure for Domino's Inkjet Printers

Domino's inkjet technology does have its drawbacks. First, the company's inkjet units are only able to make columns that are 30 droplets long, thereby limiting the height and resolution of characters that can be printed. Second, a typical Domino inkjet unit is broken down about one per cent of the time. Because the company's technology is frequently applied in continuous process industries that run 24 hours per day—like food packaging, for example—these breakdowns can result in significant amounts of lost revenue for Domino's customers. Third, the inks themselves are a source of difficulties. The chemical volatility that allows the inks to dry on non-absorbent surfaces causes them to be messy, dangerous to workers in extreme vapour concentrations, and environmentally unfriendly. And fourth, because they are a consumable input, the inks represent a recurring and significant expense to Domino's customers over the long-term.

6.4.2 Outsourcing Strategy

Domino's core competencies and competitive advantage are rooted in the unique features of its printing systems, and the company's managers are therefore very protective of the more proprietary elements of the technologies underpinning Domino's printing systems. The company accordingly attends to most of its design and development work in-house. However, the subsystems used in Domino's inkjet and laser systems are entirely manufactured by suppliers and delivered to Domino as finished units. "We assemble. We just don't have that much internal manufacturing capacity, and I don't see this changing anytime soon," said the firm's Technical Director.[38] The firm's internal engineering team does all the detailed design work, and then passes on the necessary specifications to Domino's top-tier suppliers.

This strong emphasis on intellectual property within the company is reflected in its pronounced focus on R&D. While a considerable fraction of Domino's research activity occurs within the firm, a significant amount is carried out jointly with external collaborators such as suppliers or university laboratories. Domino's managers have two principal motives for forging these types of partnerships. First, they allow Domino to leverage its own internal research capabilities by sharing costs with other firms. Second, these arrangements increase the amount of exposure that Domino has to outside organizations, thereby heightening the company's awareness of external developments. These types of alliances do not usually result in research staff being physically relocated either to or from Domino's R&D facilities; instead, researchers from Domino and the collaborating organizations collectively work towards their objectives via a series of short visits to each other's research centres. These types of research-based relationships tend to be open-ended, and have lasted for periods as short as a few months or as long as four years.

A natural consequence of Domino's preference for purchasing completed modular subsystems is that its principal suppliers are relatively skilled. Any attempt by Domino's managers to shift production to a new top-tier supplier could result in Domino having to incur quality validation and training costs as high as half a million dollars. The company's managers consequently prefer to hang on to suppliers as long as possible. In an effort to avoid these expenses, Domino's managers usually prefer to forge ties with suppliers who are large and financially stable enough to weather short-term downturns and crises in the market. In fact, one senior manager estimated that most of the company's principal suppliers are larger than Domino itself. The company also avoids relationships with firms for which Domino would represent more than 30 per cent of the supplier's total revenues.

At the same time, however, the company's management team is prepared to sever these links if a supplier is not working hard to reduce costs and improve its product and process technologies. Domino's managers apply what they refer to as their "meet and compete" policy: to remain in the

[38] Dr. Rick Mitchell. Personal communication with author, 3 July 2003.

supply network, firms must meet Domino's ambitious expectations for improvement while remaining competitive with other firms in the outside market. "We will always give our suppliers a chance to change, but we won't be constrained if they can't," said one of Domino's executives.[39]

Because inkjet printing has been available for many years, however, the technology is fairly well established, and there are several firms in the market that can provide most of the "semi-commoditized" components that go into an inkjet printing system. Rival manufacturers of inkjet units therefore often use the same suppliers as Domino for many of the non-proprietary components such as ink pumps and valves. Domino's managers feel relatively comfortable purchasing these kinds of strategically unimportant items from a single supplier so that they can reduce their costs by capturing the available economies of scale. If one of the suppliers providing components for Domino's inkjet printer systems suddenly becomes incapable of fulfilling this role, Domino's managers can quickly and easily work out an alternative arrangement without negatively impacting the other firms in the supply network.

But there are a few notable exceptions to Domino's general approach to outsourcing for inkjet units. The inks and solvents that are supplied to Domino's inkjet customers are tailored for the company's own printers, and users of these systems are therefore a captive market. Domino makes a very high profit on these items and, because of the significant role that solvents and inks play in Domino's overall revenue stream, the company prefers to manufacture these items internally. To make inks and solvents, Domino buys chemicals and pigments on a commodity basis from non-specialist vendors, and mixes them at an in-house facility.

6.5 The New Technology: Laser Printing

6.5.1 The Technology

Laser printing can print permanent, variable markings on a wide range of surfaces. Domino's current laser printers use CO_2 lasers that can essentially print any kind of image, ranging from alphanumeric data to pictures and graphics. Depending on the type of material being printed on, the laser beam vaporizes the surface material (e.g. on paper or cardboard), causes a visible surface

[39] Simon Bradley, CEO of Domino's laser printing division. Personal communication with author, 16 July 2003.

change (e.g. glass or plastics), or reacts chemically to change the colour of the bits of material that are exposed to the laser (e.g. materials with thermal coatings). The result is a crisp, permanent image that will never smudge or smear. There are indeed some materials—especially metals—that are very hard to mark with lasers.[40] But these limitations are outweighed by this technology's obvious advantages: it involves no consumable chemicals, it is not messy, it results in virtually no environmental problems, and the system has virtually no downtime.

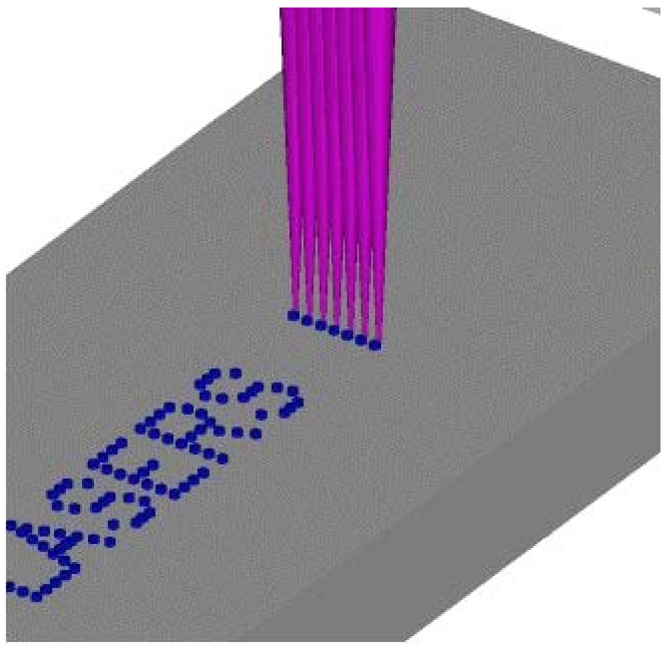


Figure 6.4: Domino's Seven-Tube Dot Matrix Coder [41]

The laser light used in Domino's units is created within a sealed tube that has mirrors mounted on both ends. The tube is filled with carbon dioxide (CO_2) gas, and when the gas is excited externally by radio frequency (RF) energy, its molecules absorb energy. Upon reaching a point of "spontaneous emission," a photon is emitted. The energy levels within these photons are amplified as they bounce back and forth along the length of the tube between one mirror, which is fully reflective, and the other, which is partially transmissive. When a critical energy level is

[40] In fact, these types of materials can often be marked by lasers that use very short wavelengths of light, but shorter wavelengths can cause serious eye damage. In the interest of workplace safety, and to avoid the long arm of American litigation, Domino adheres rigorously to a company-wide "eye-safe" policy that prohibits the design or manufacture of lasers that use potentially harmful wavelengths of light.

[41] Source: http://www.domino-printing.com/technology/laserprint.html (21 July 2003).

achieved, a pulse of heat radiation is emitted to form the laser beam. The laser light is then focused with lenses to produce precise beams of energy for printing and marking.

Domino is currently manufacturing two different designs of laser printer: dot matrix printers and scribing laser units. As illustrated in Figure 6.4, the basic concept behind the dot matrix system bears a remarkable resemblance to the company's inkjet printing technology. Seven small, high-powered laser tubes are arranged in a straight line inside the unit's printing head. Each of the lasers can be switched on and off to create between zero and seven dots in a column at one time. Two-dimensional images can be created by moving the surface being printed, resulting in dot matrix characters. This design of laser printer is simple and has no moving parts, which allows the system to print very quickly.

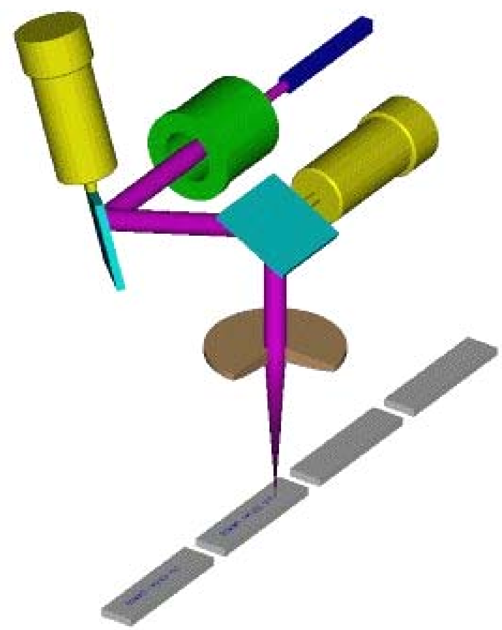


Figure 6.5: Domino's Scribing Laser Printer [42]

[42] Source: http://www.domino-printing.com/technology/laserprint.html (21 July 2003).

Domino's scribing laser systems are based on a single, continuous laser beam that is guided by two orthogonal mirrors that are controlled by fast-moving galvanometer assemblies. The scribing laser system, shown in Figure 6.5, is considerably slower than the dot matrix systems, but can generate a higher quality image because of its continuous beam.

As with the inkjet printers, each laser printing unit consists of several modular subsystems that are manufactured separately and put together. Several parts of Domino's laser printing system—specifically, the electronics, display systems, and cabinets—are very similar in both form and function to what is used in the inkjet units. But as shown in Figure 6.6, there are also some essential subsystems in the laser technology that are not found in the inkjet units. Lasers effectively burn a mark onto the printing surface, and an extraction system is necessary to take away any undesirable fumes brought about by this process. A mirror deflection system is required in the scribing laser systems (but not in the dot matrix units) to navigate the laser beam across the printing surface. RF power sources are needed to provide the energy by which energy is imparted to the CO_2 gas until photons are generated. Ceramic laser tubes are required to contain the photons until they reach a point of "spontaneous emission," and the lenses are necessary for focusing the resulting laser beam.

6.5.2 Outsourcing Strategy

While Domino's managers recognized in the early 1990s the impact that laser technologies could potentially make on the industrial printing market, the company did not have an in-house skill set that readily lent itself to developing these kinds of systems. The physical principles underlying lasers is fundamentally different from what is used to design inkjet printers. Accordingly, the company's top engineers soon realized that, in spite of their lack of familiarity with lasers, they had to move towards this technology quickly and aggressively. In the words of the Technical Director, "The technology was evolving so quickly that we were convinced that we would be left out in the cold for subsequent generations of the technology if we didn't get on board right away."[43]

The company's senior managers converged on a strategy that almost instantly provided them with the in-house competencies they were lacking: they acquired Directed Energy, a smaller company

[43] Dr. Rick Mitchell. Personal communication with author, 3 July 2003.

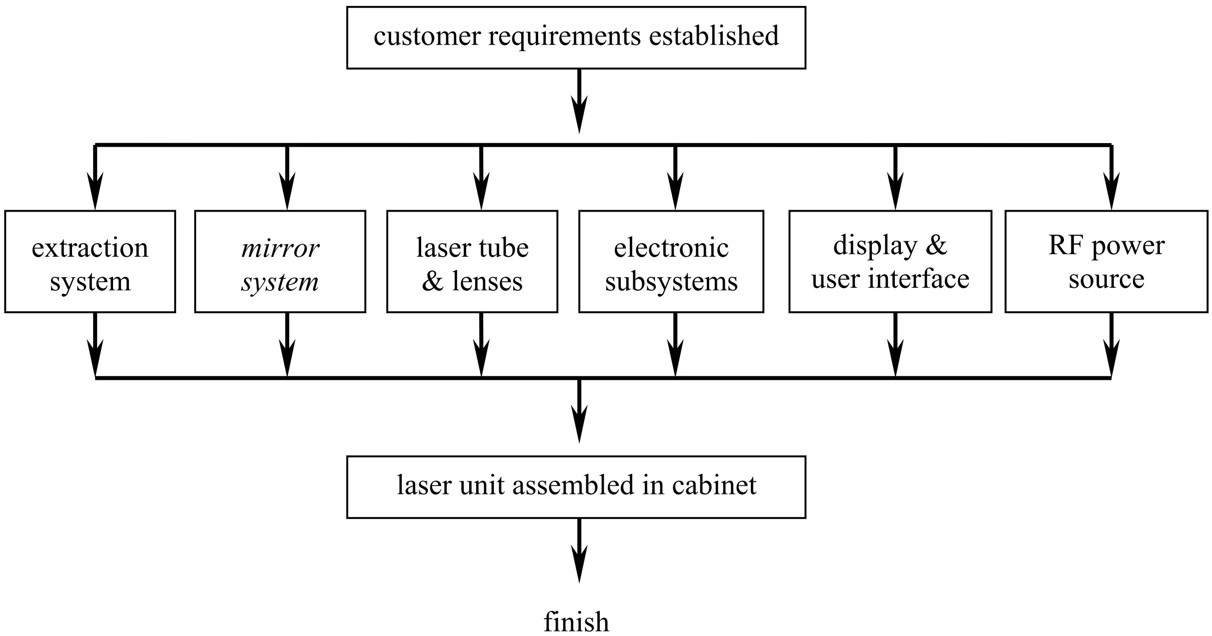


Figure 6.6: Manufacturing Procedure for Domino's Laser Printers

in California that already had a successful laser printing system for sale, but that did not have Domino's presence in the industry. Remaining true to its longstanding emphasis on intellectual property, Domino's strategy did not hinge so much on Directed Energy's existing products as it did on the company's personnel. The long-term motive for the acquisition was to develop a strong internal core of expertise in laser printing technologies. Dr. Lee Sutter, the Chief Technical Officer of Directed Energy at the time of the takeover, figured prominently in Directed Energy's overall skill base, and Domino's managers were instructed to do whatever it took to entice Dr. Sutter to stay with Domino after the acquisition. Their efforts were successful, and Dr. Sutter has remained with Domino's R&D team to the present day.

Domino has gone on since that time to acquire other smaller firms with highly focused expertise in laser printing technologies. Sator Laser, a firm based in Germany that specializes in laser scribing systems, was purchased a few years ago. And as in the case of Directed Energy, Domino has worked diligently to protect its investment in Sator's intellectual property by "ensuring that we keep the 'miracle guys' on Domino's side."[44]

[44] Dr. Rick Mitchell. Personal communication with author, 3 July 2003.

Because so much of Domino's growth as a company over the last ten years has occurred by acquisition, it has essentially inherited the supply chains of the firms that it purchased. One somewhat cumbersome consequence of this is that Domino has a relatively high amount of duplication and overlap in its supply base. Some components—like the display and user interfaces, for example—are currently made by a handful of different suppliers who are using several appreciably different design concepts. The job of managing these suppliers is made harder still by the fact that they are sporadically distributed throughout the US and Europe. Over time, however, Domino's managers hope to rationalize the company's supply chain by strategically using their internal R&D competencies to design components in such a way that they can be used in as many Domino printers as possible. A more standardized design platform would in turn make it possible to procure larger volumes of similar components from a smaller number of top-tier suppliers. This process of consolidation is already underway: whereas Domino's laser printing division relied on 170 suppliers only a few years ago, it now buys all of the necessary subsystems and inputs from only 40 firms.[45]

There are limits to how much supply chain consolidation Domino's managers want to engage in with respect to the company's laser printing units, however. Unlike the semi-commoditized components used in inkjet printers, laser marking is a significantly less mature technology, and there are therefore fewer companies in the marketplace who have the required skills and equipment to supply these types of inputs. Failed suppliers cannot be easily replaced. Thus, to minimize the degree of vulnerability in Domino's laser printing supply network, the company prefers to buy some of the more critical subsystems from multiple suppliers. Domino's managers value their relationships with these companies, and hold weekly phone conferences with them to address any problems before they grow in scope or scale.

6.6 Why This Was a Radical Innovation

When lasers were first being introduced to the industrial printing market, Domino did not have the competencies required to take advantage of the new technology. Moreover, as demonstrated by their decision to acquire smaller laser printing companies, Domino's managers recognized that the new technology was so fundamentally different that their company could not internally

[45] Simon Bradley. Personal communication with author, 16 July 2003.

develop these skills within a reasonable timeframe. And when Domino bought smaller firms such as Directed Energy to acquire this know-how, Domino's traditional supply base was entirely unable to provide the skills and equipment required to manufacture the new printing systems. Some of the suppliers that Domino has used for years to provide subsystems for its inkjet printing units are now also able to manufacture subsystems for the laser printers—but only after Domino invested a considerable amount of money to rationalize its supply chain. Laser printing was therefore a radical innovation because it was built upon an entirely new set of scientific principles and skills that was quite different from what both Domino and its traditional suppliers had used in previous generations of industrial printing systems.

6.7 Chapter Summary

This chapter discussed the circumstances underlying the make-buy decisions behind Domino Printing Science's transition from inkjet printing to laser printing, and shed light on the motives and circumstances that led to the company's outsourcing decisions throughout this technological step-change. Then it examined the relationships between Domino and its principal suppliers during the shift to laser printing. Towards establishing how make-buy decisions might be different for slow clockspeed firms, the next chapter will discuss the introduction of Twister Cyclone separators into the upstream oil and gas industry.

Chapter 7: Slow Clockspeed Case Study—The Introduction of Twister's Cyclone Separator

This chapter has four principal objectives. First, it will explain why Twister BV, a supplier of cyclone separators to the oil and gas industry, can be categorized as a slow clockspeed business unit. Second, it will discuss the make-buy decisions behind the Twister cyclone separator as it was being introduced into the marketplace, and explore the motives and circumstances that led to the company's outsourcing judgments during this period. Third, this study will discuss the relationships between Twister BV, its suppliers, and Royal Dutch/Shell. Fourth, it will demonstrate how and in what ways the transition from traditional gas dehydration systems to Twister cyclone separators is a radical technology jump.

7.1 Establishing Twister as a Slow Clockspeed Organization

Because Twister BV is only a few years old, it is somewhat difficult to gauge the clockspeed of the oil and gas industry by looking exclusively at evidence within the company. However, Fine (1998, p. 239) specifically identifies the petrochemicals sector as a slow clockspeed industry: new product technologies are typically introduced every 10-20 years, process technologies change every 20-40 years, and the sector tends to undergo a period of major organizational restructuring every 20-40 years. The upstream oil and gas industry supplies the principal inputs—that is, oil and natural gas—to the petrochemical sector, and many energy giants such as ExxonMobil, Shell, and BP have vertically integrated both the upstream and petrochemical elements of the oil and gas value chain. The two sectors are therefore tightly linked and have comparable rates of evolution. Thus, because Twister's separators are exclusively intended for use by upstream oil and gas firms, it follows that Twister BV is also a slow clockspeed organization.

The categorization of the energy sector and Twister BV as slow clockspeed is also supported by anecdotal evidence from within the industry. The CEO of Shell Technology Ventures confesses that upstream oil and gas companies are relatively risk averse, and that innovations are often adopted very slowly because energy companies tend to wait patiently for new concepts to be validated and given credibility elsewhere before adopting them (Hilliard, 2003).

7.2 Company Description and Industrial Context

Although Twister BV is officially a standalone company consisting of only 20 employees, it is attached in many ways to Royal Dutch/Shell, Europe's second-largest energy group (Hoyos, 2004). Shell owns Twister in its entirety, and several of Twister's executive-level managers are former Shell employees who resigned from their positions within Shell to lead the new venture. Moreover, Twister BV's head office in the Netherlands is tellingly located only a few kilometres from Shell's Exploration and Production R&D laboratories in Rijswijk.

Twister BV ultimately began when a handful of Shell executives diagnosed a longstanding problem within the energy industry in general, and specifically within their own company. They believed that the oil and gas sector could benefit significantly from the deployment of innovations, but observed that new technologies were absorbed into the industry very slowly. Considered by some to be "the world's biggest business" (Yergin, 1991, p. 779), the oil and gas industry has an uncommonly high profile in the global economy, and energy companies are therefore very sensitive about issues such as safety and reputation. In the words of one industry insider, "the cost of failure is very high" (Hilliard, 2003, p. 29). An unfortunate consequence of this heightened sensitivity, however, is that oil and gas firms have historically been very conservative, and are often reluctant to make use of promising new technologies.[46]

Towards helping Shell to overcome this problem, the company decided in the late 1990s to establish Shell Technology Ventures, an organization with a mandate "to mentor and assist smaller innovators to bridge the precarious gap between a brilliant dream and a workable reality"

[46] This is not to say that the industry has never made any bold forays into new technology areas. In a bid to diversify outside of the energy industry, Exxon invested nearly $2 billion in the 1970s to develop office equipment such as word processors, fax machines, and electronic typewriters. But as Utterback (1994) explains, the company later "retreated to the oil patch after selling its product line to Lanier for pennies on the dollar" (p. 14).

(Hilliard, 2003, p. 29). The company's reputation as a leader in innovation has been a driving force behind its status as a "producer of choice" in many countries over the years (Conn & White, 1994), and Shell's managers agreed that this reputation would only become more important in the future. But the CEO of Shell Technology Ventures believes that "Technology is not an end in itself. It's an enabler. Being a technology leader allows us to position ourselves better, and makes sure that we can see before our competitors where the best acreage is."[47] To this end, Shell Technology Ventures was established to stimulate innovation outside of the company, and to complement Shell's own internal R&D efforts with new technologies that were being developed externally.

One particular outside technology that caught Shell's attention was a novel system for removing condensed droplets from flowing gas streams in air conditioning systems. Noordwijk Technologies,[48] a Dutch design and engineering company with nearly 20,000 employees, did not originally have the oil and gas market in mind when it developed this technology. Nonetheless, a manager in Shell heard about Noordwijk's research in this area, and wondered if their innovation could separate droplets from natural gas as well as it could in air conditioners.

7.3 The Role of Gas Dehydration Equipment

Natural gas does not come out of the ground in a form that is ready for immediate sale. Instead, it is usually mixed with water and other substances that are usually quite undesirable for natural gas customers because they negatively affect the calorific content of the gas. Upstream providers therefore have to dehydrate the gas—that is, remove most of the water—before selling it (Campbell, 1998, p. 32).

There is more than one way to remove water from natural gas. The most common method for dehydration entails passing the gas through triethylene glycol (TEG) in a contactor. The equipment and technology behind this approach have been a staple of the industry for decades. But a small number of production sites are now using Twister separation systems. This technological step-change has the potential to impact the supply network of the upstream oil and

[47] Erik Vollebregt, CEO of Shell Technology Ventures. Personal communication with author, 18 August 2003.

[48] This is not the real name of the company.

gas industry quite noticeably and, as the new innovation is slowly adopted by energy companies, to significantly change the engineering fundamentals of oil and gas production.

7.4 The Old Technology: TEG Contactors and Reboilers

7.4.1 The Technology

TEG is a liquid alcohol ($C_6H_{14}O_4$) that readily attaches itself to water. As shown in Figure 7.1, "wet gas"—the term used to describe unprocessed gas laden with water vapour—is first passed through a separator to knock out water and heavier hydrocarbons that are entrained in the flow stream. Then the gas proceeds to the bottom of the contactor where it slowly percolates upward through successive layers of "bubble trays" that are each covered by a thin layer of TEG. As the gas is bubbled through the layers of TEG, the water vapour in the gas is gradually removed. The "dry gas" then exits from the top of the contactor.

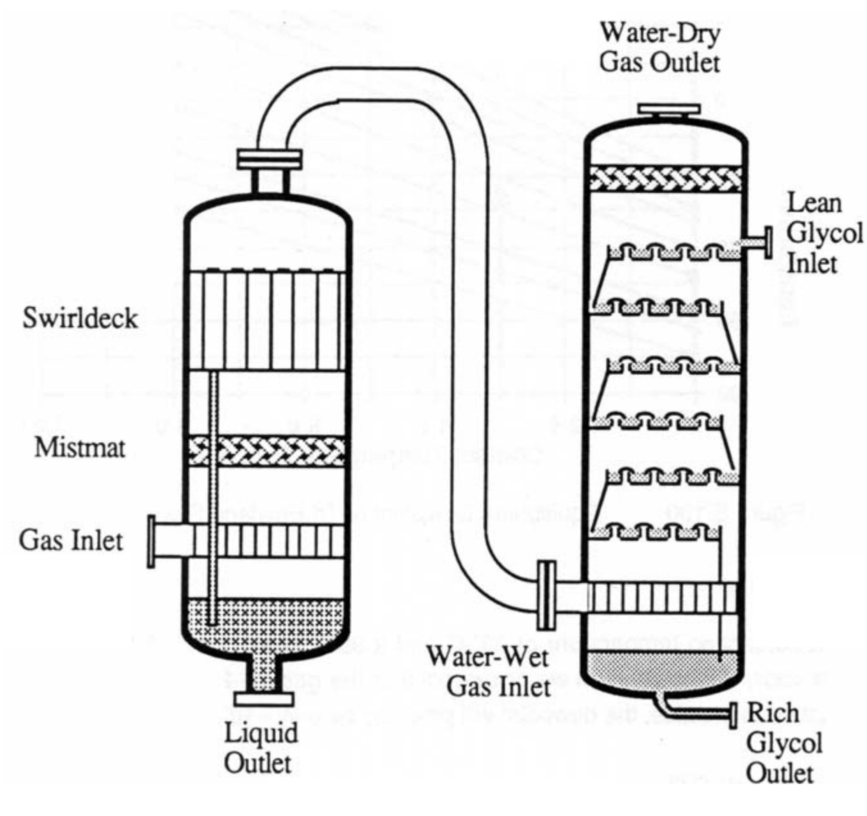


Figure 7.1: A Typical Separator and TEG Contactor

But the resulting water-TEG mixture represents an entirely new problem. A gas processing facility usually requires several tons of TEG, which costs between $0.41 and $0.66 per pound.[49] Users are therefore eager to recycle as much TEG as possible. As well, the amount of glycol that oil and gas production sites can release into the environment is heavily regulated by many countries' governments. Sites using TEG-based dehydration systems are therefore usually equipped with a series of "reboilers" for removing water from "rich" TEG. Because TEG has a higher boiling point than water, the process of taking water out of TEG is relatively simple. Heat is applied to the rich TEG within the reboiler until the water boils off, leaving behind regenerated "lean" TEG. The hot glycol is then cooled via a heat exchanger, and can be pumped back into the contactor once again.

The simplicity of glycol-based dehydration systems lends itself to a relatively straightforward manufacturing process. The production of separators, contactors, and reboilers are essentially quite similar, and are very often carried out by a single supplier who sells all of these components together as a complete "gas dehydration system." As shown in Figure 7.2, sections of plate steel are cut and formed for the outer shell of the vessels. Internal components are then attached inside: mist mats and swirl decks are added to separators, bubble trays are installed in glycol contactors, and U-tube or parallel tube heater elements are inserted into reboilers. The outer shell elements of the vessels are then welded together, automatic control systems are attached, and the finished units are tested prior to commissioning.

Despite their established reputation within the energy industry, however, TEG-based dehydration systems are not without problems. In an effort to lower costs, improve safety, and minimize environmental impact in offshore environments, oil and gas companies have progressively moved towards unmanned platform designs that export wet gas through pipelines to onshore dehydrating facilities. But dehydrating the gas onshore also introduces a host of secondary technical and operational difficulties. First, the water content in the untreated wet gas can mix with CO_2 and other trace compounds to form acids that corrode the undersea pipelines. Anti-corrosion chemicals can be added to the wet gas to inhibit the degradation of the pipeline, but this clearly represents an additional operational expense.

[49] Source: http://www.findarticles.com/cf_dls/m0FVP/1998_Oct_19/53117707/p1/article.jhtml (19 February 2004). This price range is based on market conditions during the period 1982-1997.

Second, water and heavier hydrocarbons can condense within the relatively cool pipelines and accumulate over time. To make sure that these pools do not become unmanageably large, a rubber sphere must be periodically sent through the pipeline to sweep the liquids toward the onshore drying and processing facility. Known within the industry as "sphering" or "pigging," this procedure can consume thousands of man-hours throughout the life of the production system, and can result in the release of hydrocarbons that are somewhat damaging to the environment (Herbert & Perrons, 2000).

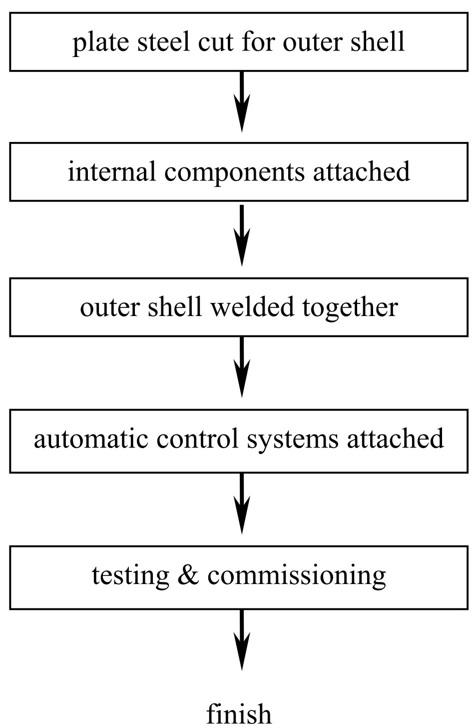


Figure 7.2: Manufacturing Procedure for Separators, Contactors, and Reboilers

Third, a high concentration of water in pressurized natural gas pipelines often results in the formation of frozen "hydrate" crystals (Campbell, 1998, p. 162). Consisting of a molecular lattice made of ice and hydrocarbons, hydrates can accumulate in pipelines and, if left unabated, may result in equipment shutdowns that can lead to hundreds of thousands of dollars in lost production. Several well-established technical solutions such as glycol inhibition and methanol injection are available for preventing the formation of hydrates, but these preventative measures usually represent a non-trivial expense both in terms of capital investment and long-term operating costs.

7.4.2 Outsourcing Strategy

The simplicity of traditional TEG-based dehydration technology has given rise to its ubiquity in the industry over the last few decades. The manufacturing specifications for these pieces of equipment are governed according to universally available standards and guidelines, and units of comparable quality and price can therefore be purchased via catalogues from dozens of vendors around the world. The same is also true for TEG, which is a feedstock to a broad range of products such as plastics, coating resins, and textiles. Because dehydration units and TEG are essentially commodity items, they offer very little strategic value to the firms that use them.

7.5 The New Technology: Twister Cyclone Separators

7.5.1 The Technology

Twister separators do not have any moving internal parts and do not require any kind of chemicals for day-to-day operation. Instead of using TEG to dehydrate natural gas, Twister technology achieves this same result by using centrifugal force to artificially increase the "g's"[50] that the gas flow stream is exposed to.

As illustrated in Figure 7.3, a Laval nozzle is used to expand the inlet gas, thereby causing it to accelerate almost instantly to supersonic velocities. This rapid and nearly isentropic expansion also sharply reduces the temperature of the flow stream, which in turn triggers a process of condensation in which water vapour and heavier hydrocarbons change phase to become small droplets. The two-phase mist then passes over a metal wing that is positioned on an angle to the axis of flow, causing the flow stream to rotate at very high speeds.

The resulting centrifugal forces, which can be in excess of 300,000 g's (Okimoto & Brouwer, 2002), cause the small liquid droplets to accelerate towards the outside of the swirling flow stream where they are separated and removed. The dry gas then flows into a diffuser where the

[50] A "g" is a unit of force equal to the force exerted by gravity, and is used to indicate the force to which a body is subjected when it is accelerated. Source: http://www.thefreedictionary.com/g-force (11 February 2004).

velocity is significantly reduced and the pressure is increased to approximately 70-80 percent of the inlet pressure. As well, because a standard Twister tube is only 1.6 metres long, the supersonic velocity of the gas results in a residence time of less than one second. The kinetic molecular reactions that create hydrates take significantly more time than this, and hydrates are therefore prevented from forming at any point throughout the drying process.

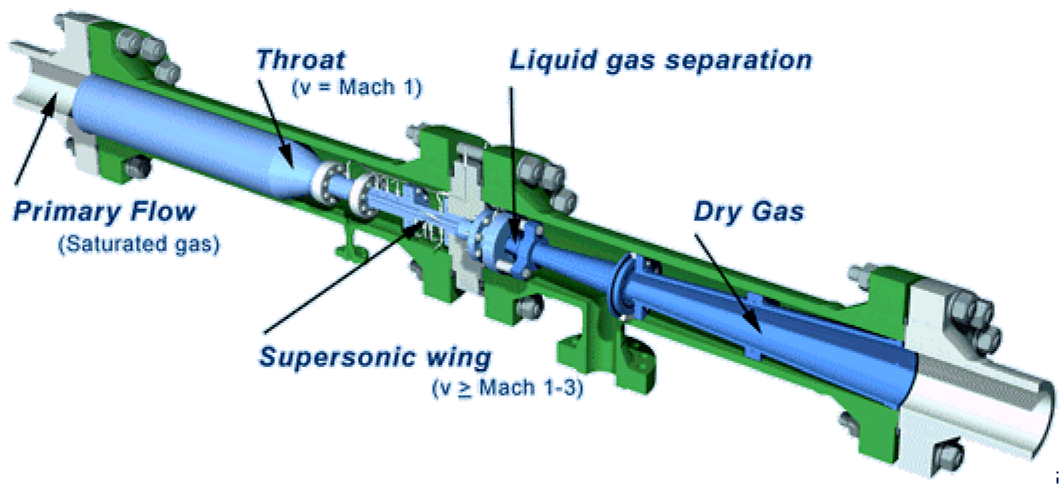


Figure 7.3: The Twister Cyclone Separator—Cross Section[51]

A typical Twister tube can process approximately three million standard m^3 of natural gas per day. But a normal production facility can process many times this amount and, as shown in Figure 7.4, Twister separator tubes can therefore be joined together by a manifold to accommodate a customer's specific throughput requirements. Their small size, reliability, and low weight make Twister an attractive option for unmanned offshore environments inasmuch as gas can immediately be dehydrated at the production site, thereby eliminating all of the operational and technical difficulties normally associated with transporting wet gas to an onshore dehydration facility.

[51] Source: http://www.twisterbv.com/ (10 February 2004).

Each Twister separator is not the same as all the rest, however. The broad range of oil and gas well compositions and the wide spectrum of customer requirements makes it necessary for Twister's engineers to customize many aspects of the Twister technology before it can be applied in a particular situation. Therefore, as shown in Figure 7.5, the first step in manufacturing a Twister separator is to conduct a comprehensive study to ascertain what the customer will require.

Figure 7.4: Multiple Twister Cyclone Separators Joined by a Manifold[52]

A team of engineers studies the context of the situation: what types of process requirements will the separators have to fulfil, and where is the production system located? A cost estimate is prepared for the customer so that they can decide whether or not Twister separators would add an amount of value to their production system that would make the technology worthwhile. If the customer decides to install Twister units, highly specialized computational fluid dynamics (CFD) software is used to determine the optimal profile and basic tube dimensions for the customized separators. The basic dimensions are then translated into a detailed design from which the components can be produced to extremely tight tolerances. The components are then assembled, and the finished separators are installed in the production system. Because of the strong emphasis

[52] Source: http://www.twisterbv.com/ (10 February 2004).

on safety within the industry, the installed Twister units must undergo a fairly rigorous commissioning process during which a wide range of controlled tests are carried out to ensure that the separator will perform as it is intended to.

7.5.2 Outsourcing Strategy

Twister BV was an extremely small enterprise in its early days, and relied heavily on its outside suppliers as a result. When the company was first trying to introduce the concept of cyclone separators to the oil and gas industry, Noordwijk Technologies was responsible for most aspects of the design and production. Specific machining requirements were met by Noordwijk's existing supplier base, and the finished products were assembled by Noordwijk technicians. Twister BV's engineers and management team at the time, many of whom had only recently left Shell, had very little previous exposure to the new technology. In its nascent stages, the firm effectively assumed the role of a "systems integrator" (Ernst & Steinhubl, 1997), offering management experience, millions of dollars in capital investment, and in-field opportunities for trying out prototypes.

In spite of Noordwijk's prominent role in the design and production process, however, the new technology also required a significant amount of outside input with regards to the aerodynamic and thermodynamic behaviour of fluids travelling at supersonic speeds. These phenomena are relatively well understood within the aircraft and aerospace sectors, but engineers in these industries tend to focus principally on supersonic flow over wings and along fuselages. It was not known if or how the principles of supersonic flow might be subtly different when rotating within a tube. Towards filling these holes in existing research, the Twister team enlisted the help of a handful of researchers from universities in the UK and the Netherlands to develop highly specialized modelling software for the CFD, thermodynamic, and manufacturing aspects of the Twister separator technology.[53]

Today, the company regards this know-how as an important part of its competitive advantage, and retains a large fraction of its R&D work in-house so that it will be able to do almost all of its

[53] Research partnerships were established with Delft University of Technology, Eindhoven University of Technology, and the University of Twente in the Netherlands; in the UK, an R&D collaborative agreement was launched with the University of Manchester.

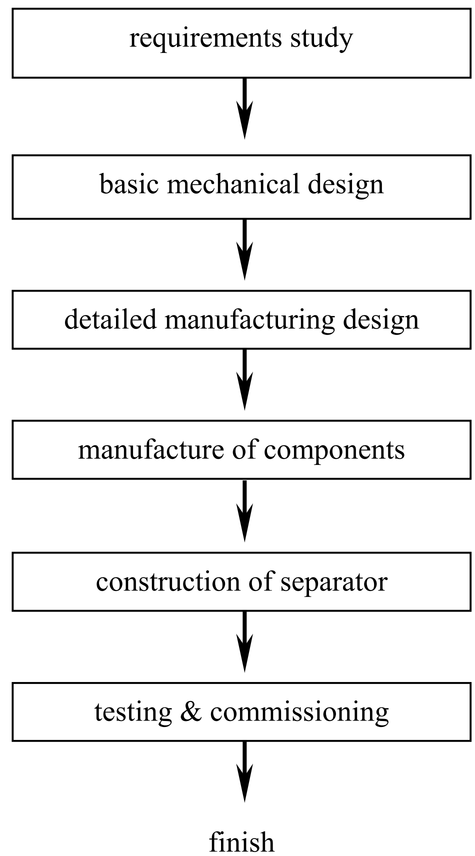


Figure 7.5: Manufacturing Procedure for Twister Separators

own design concept and process engineering work in the future. In fact, Twister BV's engineers have become so adept in this area that the company now sells its expertise in CFD and natural gas processing systems on a consulting basis to other firms as a source of supplementary revenue. But the Twister team still maintains its collaborative research relationships with the outside laboratories it worked with in the early days, and recently launched a new R&D link to Shell's high-tech Thornton Research Centre in the UK.

Not all of the relationships between Twister BV and its original partners are still intact, however. The firm's relationship with Noordwijk Technologies weakened considerably because Noordwijk's senior managers did not share Twister's optimism about the future prospects of cyclone separator technologies in the oil and gas industry. Although Noordwijk continues to design and manufacture cyclone separators for air conditioning applications, the relationship between Noordwijk and Twister BV was severed only a few years after the development of the first Twister prototypes, leaving Twister BV as the only firm to apply the technology within the energy sector.

In addition to the R&D and conceptual aspects of the technology, Twister's engineers have also taken over the basic mechanical design aspects of the manufacturing process. As before, however, the detailed design and production functions are still handed off to outside suppliers—but not the same ones that performed these tasks when Noordwijk Technologies was involved. Instead, Twister BV has developed new ties with a small number of very small, highly specialized supplier firms that each consists of between three and ten people. It is not a company policy to buy exclusively from smaller firms, but Twister's managers have observed that small suppliers tend to be flexible and more responsive to Twister's needs than their larger competitors. In the words of Twister's CEO and Technical Director, "The smaller contractors learn from us."[54] Key suppliers have sent their engineers to work alongside the Twister BV design team on a full-time basis for as long as two months. The CEO explains this practice by noting that "Having a close relationship with these companies benefits us because they come to know the context we are working in, and they know our constraints."

The company's preference for smaller suppliers does come at a price, however: Twister BV has to bear almost all of the costs associated with developing or acquiring new technologies. Almost none of the company's suppliers have financial resources that would allow them to invest in long-term R&D. As well, because of the uniqueness and highly customized nature of the parts used in Twister separators, the results of any research investment by the suppliers would very likely be applicable only to Twister BV's products. Twister's managers do not engage in long-term contracts with supplying companies, and these firms are therefore reluctant to invest heavily in new technologies for which Twister BV would be the only customer.

But the absence of long-term contracts does not mean that Twister BV does not value its suppliers. Compared to their peers in the industry, Twister managers believe that they place a relatively high premium on long-term supplier relationships. Because the industry evolves quite slowly in comparison to other sectors, most of the technologies used on a day-to-day basis within

[54] Kees Tjeenk Willink, Twister's CEO and Technical Director. Personal communication with author, 7 August 2003.

the energy industry have been available for many years, and are widely available from a broad range of suppliers. The components used to construct most oil and gas processing facilities are largely modular in nature—that is, they have standardized interfaces, and similar components can be purchased from several vendors. This is not true for Twister's separators. Many of the parts within a Twister unit are made to precise specifications and require a considerable amount of know-how on the part of the suppliers. Twister BV accordingly values the relationships it has built within its supply base because of the high degree of expertise and specialized skills that collaborating firms must have to fulfil their roles competently.

The highly specific requirements for some aspects of the technology sometimes result in situations where Twister's managers have very few procurement options, and the company's supply base consequently extends to the US and many countries in Europe. For example, one of the internal components of the Twister separator is made from molybdenum steel, an alloy that is particularly resistant to corrosion. The variety of this steel that Twister BV requires is very rare, and can only be purchased from a single vendor in the US.

Twister's managers also consider using foreign suppliers to gain competitive advantage when procuring components and inputs that are less scarce or less sensitive to intellectual property (IP) related issues. Whereas the company is currently using Dutch suppliers for about 70 percent of its detailed design and manufacturing requirements, it is considering the possibility of outsourcing some of these tasks to firms in the Czech Republic. Twister's managers estimate that significantly lower wages in that country could potentially reduce the company's manufacturing costs by as much as 40 percent.

But there are instances, too, when Twister BV is forced to outsource the production of a particular component because of offsetting and "local content" requirements. In the interest of fostering Malaysia's domestic oil and gas supply base, Malaysian government officials decided in 1998 that Twister technology could only be used by the country's nationalized oil company if some of the parts were manufactured locally. Twister BV complied with this requirement, but at considerable expense. In much the same way that offsetting is now a standard practice in the commercial aircraft industry (Perrons, 1997), the company's managers expect that offsetting will become a recurring obstacle as Twister separators gain acceptance in oil and gas production environments around the world.

Twister's managers do not expect their current outsourcing strategy to change appreciably as the Twister separator technology matures. "We try to apply a Coca-Cola approach to technology management," explained a senior engineer in the company.[55] "Our objective is to keep the IP stuff protected as long as possible." Because most of the value added by Twister BV comes in the form of IP, the Twister team works hard to ensure that its trade secrets do not fall into the hands of potential competitors. Thus, even as the technology matures, the company does not plan to outsource the functions that are directly related to its core competencies.

The company's pricing strategy also figures prominently in its decision not to outsource potentially revealing aspects of Twister separator technology. Twister BV sells its products according to a "value-based" pricing scheme as opposed to a cost-based one. Cost-based strategies typically involve adding together the costs that a company incurs en route to making a product, and then adding a profit margin on top of that. Value-based pricing, by comparison, entails arriving at a price according to how much value the customer gets from the product. Because each Twister separator has to be customized and is sold as a "total solution," it is effectively impossible for prospective customers to determine whether or not they are paying a high price. One Twister manager conceded that this strategy had resulted in impressively high profit margins in certain cases.[56] But no customer would think highly of this practice, so Twister BV has to organize its supply network in such a way that none of the firm's collaborators or customers will be able to determine the company's cost structure. If Twister BV were to rely on suppliers for too many critical aspects of the technology, their cost base would be understood by the industry, and the company would inadvertently expose its lucrative margins.

7.6 Why This Was a Radical Innovation

Neither the large oil and gas multinationals nor their established suppliers have a sufficient amount of experience with the principles of supersonic flow and high-precision design to develop internally the technology underlying Twister cyclone separators. Conversely, firms from the aerospace sector that are familiar with supersonic flow phenomena and precision design do not know much about the technical and operational realities of the energy industry. Thus, the shift

[55] Arco Langerak, a Principal Process Engineer at Twister BV. Personal communication with author, 7 August 2003.

[56] Hans Wierda, former Operations Manager at Twister BV. Personal communication with author, 10 April 2002.

from TEG-based gas dehydration systems to Twister technology therefore represents a radical jump because the innovation is based on skills that are scattered throughout two very disparate industries, and incumbent firms in either are incapable of exploiting this new technology without a significant amount of learning and investment. The methods and skills that suppliers have used for years to manufacture traditional gas dehydration equipment will be effectively rendered obsolete by this innovation.

7.7 Chapter Summary

This chapter discussed the make-buy decisions behind the Twister cyclone separator as it was being introduced into the marketplace, and explored the motives and circumstances that led to the company's outsourcing judgments during this period. The next chapter will draw together all of the quantitative and qualitative data presented in this investigation, and will discuss how these results impact the process of theory building in this research area.

CHAPTER 8: DISCUSSIONS AND CONCLUSIONS

Only one of the four objectives put forth at the beginning of this thesis remains unfulfilled: discussing the data and arriving at conclusions that are relevant to managers contending with radical innovations. Towards achieving this end, this chapter will start by reviewing the quantitative and qualitative data presented earlier, and will then explain why this evidence did not support the hypotheses developed in Chapter 2. Next, this chapter will discuss how these results impact the process of theory building in this research area. Then the conclusions arising from the data will be translated into strategic insights that can be used by decision-makers in industry to manage potentially radical innovations. Finally, this chapter will recommend directions for future research within the area of make-buy decisions in the face of radical innovation.

8.1 Hypothesis 1: Close Supplier Relationships Result in Better Performance

8.1.1 Conclusions Emerging from the Evidence

As shown in Table 8.1, both the UK and international survey data sets failed to support the first hypothesis in a meaningful way. Close relationships between customer firms and principal suppliers that were built on trust and personal relationships did not play an important long-term role in the development of potentially radical innovations among participating firms. Consequently, firms that engaged in these types of relationships did not perform demonstrably better in the long-term than direct competitors in their industry.

This supports Afuah's (2001) observations from the computer industry's leap from complex instruction set computer (CISC) architectures to the faster RISC standard. He explains that, "following a technological change that is competence-destroying to firms and their suppliers, firms that are integrated vertically into the new technology will perform better than those that are

Evidence	Outcome Predicted by Hypotheses	Actual Outcome
UK survey data	Positive correlation between majority of independent and dependent variables for medium clockspeed companies; no correlation for fast or slow firms.	Only one of the independent variables, "Values Relationships," was positively related to long-term performance for fast clockspeed firms; no meaningful link for medium or slow companies.
International survey data	Positive correlation between majority of independent and dependent variables for medium clockspeed companies; no correlation for fast or slow firms.	No independent variables were meaningfully related to long-term performance for any clockspeed group.
Fast clockspeed case study (Intel)	Close relationships between Intel and principal suppliers would not play an important role in the development of potentially radical innovations.	Intel works hard to sustain long-term relationships with suppliers, and jointly developed organic/C4 technology with them. Uneven trust between Intel and suppliers, however.
Medium clockspeed case study (Domino)	Close relationships between Domino and principal suppliers would play an important role in the development of potentially radical innovations.	Domino acquired laser printing competencies in lieu of developing them jointly with suppliers. Domino did not have resources to assist inkjet suppliers in making the transition to laser technology.
Slow clockspeed case study (Twister)	Close relationships between Twister and principal suppliers would not play an important role in the development of potentially radical innovations.	Twister relied heavily on top-tier suppliers throughout R&D phases of new technology.
Overall Conclusion	***Neither hypothesis meaningfully supported.***	

Table 8.1: Summary of Evidence

not" (p. 1211). Fine & Whitney (1996) arrive at a similar conclusion, saying that "generational breakthroughs typically require an integrated product architecture created by a vertically integrated firm, with correspondingly limited outsourcing" (p. 26). Thus, while research from the areas of lean manufacturing and supplier relationships suggests that firms can benefit from the development of these types of R&D links, these benefits appear not to outweigh the costs and difficulties associated with maintaining these ties during periods of transition involving radical innovations.

As discussed in Chapter 5, Intel applied a similar philosophy during its jump from ceramic/wire-bonded packaging to organic/C4 packaging technology. With the "open kimono" approach to information sharing demanded by Intel's packaging unit, the unit's top-tier suppliers were expected to share highly detailed cost information and technical data with Intel's managers. Intel defended this practice by insisting that this uncommonly high degree of transparency was necessary to reduce costs and improve quality. But the direction of information flow was largely one-way. While Intel does host an annual "Supplier Day" to share the company's long-term plans and intentions with principal collaborators and suppliers, this gesture clearly falls short of the "open kimono" transparency expected from Intel's suppliers.

This notable imbalance in the sharing of information between Intel and its suppliers reflects the pronounced difference in the types of trust extended by each of the parties in the relationship. By insisting that its principal suppliers provide "open kimono" access to proprietary cost data and technical information, Intel effectively demands "goodwill trust" from its suppliers. Sako (1992) characterizes this highly pervasive kind of trust as one that is rooted in an expectation of open commitment. Intel's managers fully expect their top-tier suppliers to trust them with intimate details of their operations and strategic intentions. But this is quite different from the kind of trust that the suppliers receive in return. Intel's suppliers are only privy to items of high-level strategic information that Intel wants to share, and Intel's managers concede that the company does not discuss all of its long-term objectives or detailed cost data with partners and suppliers. Intel's suppliers are therefore given a less diffuse kind of trust that Sako (1992) refers to as "contractual trust." The relationship between Intel and its principal suppliers is therefore based on a large disparity in the amount and kind of trust extended in each direction. This in turn suggests that Intel's supplier relationships are not entirely cooperative.

Intel's "Copy Exactly!" philosophy also indicates that the company does not regard its suppliers as long-term collaborators in the development of radical innovations. When Intel converges on a successful design or process with its suppliers, they quickly ramp-up production by making exact clones of the finalized manufacturing environment and faithfully duplicating the original inputs. No variables are changed or adapted whatsoever from one plant to the next. Intel's managers applied this same strategy to its packaging suppliers: when Imoko and Intel's engineers jointly overcame the organic/C4 technology's production problems, Intel's senior management team forced its two other packaging suppliers, Shinto Electronics and Nurimoto Packaging, to adopt Imoko's version of the technology verbatim. Despite the fact that both Shinto and Nurimoto had been suppliers of ceramic/wire bonded packaging to Intel for many years, Intel's managers did not continue to foster the packaging R&D initiatives underway in these companies. This decision suggests that Intel regards many of its principal suppliers not as co-collaborators, but as a source of manufacturing capacity.

This conclusion is also bolstered by the fact that Intel did not originally intend to interact with Imoko's engineers throughout the development of the organic/C4 packaging technology. Because of Imoko's long and distinguished list of achievements in the field of high-precision composites, Intel's managers set out with the assumption that Imoko should play a leading role in developing and perfecting the organic/C4 technology, and that Imoko would bear most of the costs for this. But it quickly became clear to Intel that Imoko was experiencing considerable difficulty in making this happen. Intel's design teams working on other parts of the Pentium II generation microprocessor were already basing their designs on the assumption that the organic/C4 transition would be successful, and Intel was therefore forced to assign considerable human and financial resources to help Imoko solve these problems. However, this collaborative approach was neither intentional nor a regular occurrence within Intel's supply network.

Domino Printing also did not develop long-term relationships with its suppliers for the purposes of developing potentially radical innovations. A considerable amount of Domino's R&D activity is conducted in cooperation with external collaborators such as suppliers or university laboratories. These types of partnerships allow Domino to leverage its own internal research capabilities by sharing costs with other firms and by increasing the firm's exposure to external developments. But the evidence presented in Chapter 6 suggests that this strategy is not applied to radical technology jumps. Faced with the industry's transition to laser printing, Domino's executives decided to acquire Directed Energy, a smaller company that already had a successful laser printing system for sale, but that did not have Domino's presence in the industry. This decision was principally rooted in the company's strong emphasis on intellectual property rights: in lieu of putting faith in a long-term alliance with another firm, Domino wanted to own the technology outright.

Domino's make-buy strategy for the new technology pivoted on personnel. The company's managers were instructed to do whatever was necessary to entice Dr. Lee Sutter, Directed Energy's Chief Technical Officer, to stay with Domino once the acquisition was complete. Whereas proponents of lean manufacturing and "distributed innovation" suggest that a supply network's expertise can remain intact by fostering long-term links among collaborating firms (Quinn & Hilmer, 1994; Womack *et al.*, 1990), Domino's managers eschewed this approach and directly acquired important elements of intellectual property in the new technology.

Another important consideration in Domino's make-buy plan for laser printing technology was that Domino's inkjet supply base was entirely unable to provide the skills and equipment required to develop the new printing systems. Laser printing was built upon a set of scientific principles and skills that was quite different from what both Domino and its traditional suppliers had used in previous generations of industrial printing. Domino's managers therefore found it quite difficult to help their traditional suppliers make the transition to the new technology. And unlike Intel, which had to invest nearly $250 million to help Imoko develop organic/C4 packaging, Domino did not have access to the resources that would have made it possible to help its traditional suppliers make the jump to laser printing.

Although the company is relatively young, Twister BV's make-buy decisions thus far strongly suggest that the company will also not develop long-term relationships for developing potentially radical innovations. While Twister did indeed rely quite heavily on its top-tier suppliers throughout the R&D phases of its cyclone separators, this decision was not based on any kind of overarching preference for jointly developing radical innovations. Instead, the company's early make-buy decisions were largely driven by necessity: Twister simply had too few employees and resources to fulfil these roles in-house. In the technology's nascent stages, Noordwijk Technologies helped Twister with most aspects of the design and production phases of the separators.

As Twister has grown and evolved, however, the company has severed its relationship with Noordwijk and developed many of these skills internally. Twister's managers regard this know-how as an important part of the company's competitive advantage, and Twister accordingly retains a large fraction of its R&D work in-house so that it will be able to do almost all of its own design concept and process engineering work in the future. And while the company still maintains several collaborative research relationships with outside laboratories, its most recent R&D joint venture was with Shell's Thornton Research Centre in the UK. In light of Shell's close relationship and historical ties with Twister BV, this new link with the Thornton Research Centre could reasonably be interpreted as a move towards partially internalizing Twister's R&D activities within the Shell family of companies.

8.1.2 Implications for Theory

The lack of meaningful support for the first hypothesis essentially means that, on average, there is very little strategic advantage to be had by hanging on to long-term supplier relationships when a radical technology is introduced. Firms that participated in the investigation did not perform noticeably better by preserving links with their principal suppliers. But at the same time, there seems to be little harm in maintaining these relationships: companies that did keep these links intact did not perform demonstrably worse. Hence, while a significant amount of management research (e.g. Dyer, 1996; Quinn & Hilmer, 1994; Womack *et al.*, 1990) underlines the value of these relationships during the day-to-day operations of a business, this evidence draws into question whether they are helpful in the face of a radical innovation.

One potential explanation for this outcome is that, as suggested in Chapter 2, the current system of classification applied to supplier relationships in manufacturing is not yet complete. Proponents of "virtual organizations" (Chesbrough & Teece, 1996) and lean-style supplier relationships (Womack *et al.*, 1990) frequently highlight the value of establishing long-term relationships with principal suppliers. However, the lack of support for the first hypothesis in this investigation strongly hints that there are limitations to this theoretical model of supplier management. Farsighted investments in joint R&D projects involving trusted suppliers do not necessarily improve a firm's bottom line in the long-term. The suitability of the "lean" theoretical approach discussed in Chapter 2 is contingent on whether the innovation will be radical or incremental in nature.

8.1.3 Implications for Industry

This conclusion has important implications for managers of multi-firm R&D partnerships. While many manufacturing firms have benefited handsomely by involving suppliers in the development of new technologies (Chesbrough, 2003; Quinn, 2000), these benefits appear not to be quite as pronounced when the technology is radical in nature. The decision whether to develop a new technology in-house or with a partner should therefore be heavily influenced by the technology itself—is it potentially radical? Collaborative R&D arrangements with trusted suppliers may yield long-term benefits in projects involving incremental or more modest technological developments, but these benefits may be somewhat elusive if the technology will likely be competence-destroying. As Fine & Whitney (1996) suggest, companies will probably have a greater chance of succeeding in these kinds of scenarios if they retain in-house a relatively large fraction of the value network in the early days of the new technology.

8.2 Hypothesis 2: Medium Clockspeed Firms Will Benefit More Than Fast or Slow Clockspeed Firms

8.2.1 Conclusions Emerging from the Evidence

Neither the UK nor the international survey data sets materially support the second hypothesis, either. The performance of fast clockspeed business units is only significantly linked ($p < 0.05$) to the "Values Relationships" variable in the UK population. In the international data set, none of the eight independent variables were linked to more than two of the dependent measures of firm performance. Medium clockspeed companies in both groups did not consistently benefit from long-term relationships with their principal suppliers, and extremely fast or extremely slow firms did not overwhelmingly fail to establish these links. Simply put, a firm's clockspeed did not have a measurable effect on its ability to establish and maintain long-term relationships with principal suppliers.

The case studies also point to this conclusion. In spite of the fact that major new product technologies are introduced into the fast clockspeed semiconductor industry every 1-2 years, the managers in Intel's packaging business unit worked hard to sustain their decades-long relationship with Kobe Semiconductor. As noted in Chapter 5, "supplier re-use" is an important part of Intel's manufacturing strategy, and the company goes through considerable lengths to make sure that it can preserve relationships with its key suppliers for as long as reasonably possible. Kobe's above average size in the industry and the longstanding relationship that it shared with Intel made it a valuable partner, and managers within the two companies had developed a tremendous amount of trust and rapport. Towards preserving this relationship, Intel even went so far as offering to hand over the organic/C4 packaging technology to Kobe and to train the supplier's engineers to become proficient with the new technology. But in the end, Kobe decided to sever its ties with Intel's packaging business unit.

Twister BV, a slow clockspeed business unit, also expressed a preference for working with suppliers it has dealt with in the past. The company's CEO explained this practice by noting that "having a close relationship with these companies benefits us because they come to know the context we are working in, and they know our constraints." Compared to their peers in the upstream oil and gas industry, Twister's managers believe that they place a relatively high premium on long-term supplier relationships. Many of the components within a Twister unit are made to precise specifications and require a considerable amount of know-how on the part of the suppliers. Twister BV accordingly values the relationships it has built within its supply base because of the high degree of expertise and specialized skills that collaborating firms must have to fulfil their roles competently.

Conversely, Domino Printing, a medium clockspeed business unit, did not consistently base its make-buy decisions on long-term supplier relationships. Domino's managers typically prefer not to shift production to new suppliers because of the high validation and training costs associated with such a move. At the same time, however, Domino's management team is also quite at ease with the thought of severing these links if a supplier is not working hard to reduce costs and improve its product and process technologies. Remaining true to the company's "meet and compete" approach to supplier management, one Domino executive emphasized that the company can and does change suppliers if an existing collaborator is getting in the way of Domino's aspirations. Moreover, while Domino does engage in a significant amount of joint development activity with external partners such as suppliers or university laboratories, these types of relationships do not usually result in research staff being physically relocated either to or from Domino's R&D facilities. Instead, researchers from Domino and the collaborating organizations collectively work towards their objectives via a series of short visits to each other's research centres. One Domino manager indicated that these relationships tend to last less than four years—which is significantly shorter than the decades-long relationship established between Intel and Kobe Semiconductor in an industry with a considerably faster clockspeed.

While failing to offer support for the second hypothesis, however, the case studies do help to explain why industry clockspeed is not an important factor in supplier relationships throughout the development of potentially radical innovations. Throughout their respective periods of transition, Intel, Domino, and Twister all regularly and routinely dealt with suppliers from industries that had clockspeeds that were different from their own. For example:

- Twister BV, whose products are exclusively intended for use by the slow clockspeed upstream oil and gas sector, relied heavily on outside organizations to develop highly specialized modelling software for the CFD, thermodynamic, and manufacturing aspects of the company's separator technology. Fine (1998) specifically points to software engineering as a fast clockspeed industry.

- Domino, a medium clockspeed company, outsources the production of its electronic subsystems to an outside firm. But electronics firms are, according to Fine's (1998) definition, fast clockspeed organizations. Moreover, on the other side of the clockspeed spectrum, Domino purchases cabinets and housings for its laser units from a company that has not appreciably changed its product line in decades.

- Intel's managers readily concede that the fibreglass matrix used in the company's new organic/C4 packaging designs is not by itself a novel development in the industry. Imoko Composites had been manufacturing high-precision epoxy and fibreglass molding systems for decades before Intel's engineers considered using the technology, and the company had been working specifically on developing C4 arrays on organic substrates for ten years prior to establishing a partnership with Intel. Imoko's much slower rate for introducing new product technologies roughly falls within the 4-10 years window that Fine (1998) offers as a defining characteristic for medium clockspeed industries such as bicycle manufacturing or the automotive sector. This rate of evolution is clearly much slower than Intel's.

Many of today's products "are so complex that no single company has all the necessary knowledge about either the product or the required processes to completely design and manufacture them in-house. As a result, most companies are dependent on other firms for crucial elements of their corporate well-being" (Fine & Whitney, 1996, p. 1). The majority of firms rely on outside suppliers for components, inputs, or know-how (Doz & Hamel, 1997; Wilkinson & Young, 2002). However, the three cases examined in this investigation highlight that these suppliers frequently come from industries with dramatically different clockspeeds. The nature of the relationship between a supplier and a customer may therefore be a product not only of the customer's industry, but of the supplier's too. Accordingly, the clockspeed of the customer firm by itself seems to offer little insight into the character or dynamics of a supplier relationship.

The role of clockspeed definitions in make-buy decisions is weakened further by the fact that many companies offer a range of products with markedly different rates of evolution. The 3M Corporation is a particularly poignant example of this. Founded in 1902 as a provider of mineral deposits for grinding wheel abrasives, 3M currently has a highly diversified portfolio of products designed for customers in the health care industry, safety and security services, the communications sector, and the transportation industry.[57] Despite this broad range of very disparate technology areas that evolve at different rates, however, the company's managers attribute much of 3M's success to a surprisingly unified corporate culture (Collins & Porras, 1996). It therefore follows that firms like 3M cannot be neatly classified as belonging to a single clockspeed group. Businesses that behave like fast clockspeed organizations in certain situations may act like slow clockspeed organizations at other times, and vice-versa.

8.2.2 Implications for Theory

Chapter 2 posited that the scheme of categorization used to analyze make-buy decisions in the face of radical innovations is not yet complete. As Christensen & Sundahl (2001) contend, an incomplete categorization system does not in any way discredit prior work; it merely suggests that "[t]here must be something else going on here" (p. 10). Underpinning the second hypothesis was the belief that at least part of this "something" could be explained by the clockspeed of a particular company. However, the lack of meaningful support for this hypothesis suggests that industry clockspeed is not a relevant variable in the theoretical classification of radical innovations.

8.2.3 Implications for Industry

Many of the prescriptive frameworks and strategic formulas put forward in the literature for make-buy decisions involving radical innovations are based on observations from fast clockspeed industries. Focusing on the computer industry, Afuah (2001) concludes that, "following a technological change that is competence-destroying to firms and their suppliers, firms that are integrated vertically into the new technology will perform better than those that are not" (p.

[57] Source: http://www.3m.com/about3m/facts/CorpFacts.jhtml (12 May 2004).

1211). Harrigan (1984) offers evidence from the memory chip sector which shows that make-buy decisions are often based on the amount of learning that can be gained by doing something in-house. Citing Christensen's data from the hard disk drive industry over several product generations, Fine & Whitney (1996) observe that "generational breakthroughs typically require an integrated product architecture created by a vertically integrated firm, with correspondingly limited outsourcing" (p. 26).

But different industries often behave in profoundly different ways in the face of new technologies (von Hippel, 1988), and managers in a slow or medium clockspeed sector could quite reasonably wonder if the findings from these earlier research efforts are immediately and directly relevant to their particular case. Are lessons gleaned from the computer industry, for example, only relevant to other computer companies? The relative insensitivity of make-buy decisions to industry clockspeed effectively broadens the potential applicability of several prior investigations involving the management of radical innovations. Lessons learned in one particular industrial context need not be discarded by managers in other industries with faster or slower rates of evolution. This is not to suggest that any framework or prescriptive formula could ever be equally applicable in every manufacturing environment. But as industry decision-makers gradually identify the contingencies and variables that most dramatically impact their make-buy decisions, this investigation's findings suggest that they can confidently ignore industry clockspeed.

8.3 The Role of Firm Size

Another particularly noteworthy outcome from both the surveys and the case studies is that firm size does indeed play a role in make-buy decisions concerning potentially radical innovations. As Schumpeter (2000) suggests, large firms are less sensitive than small ones to short-term profit constraints. International corporations like Intel have both the financial resources and the manpower to explore farsighted new technology areas that are not tightly bound to their short-term revenue stream. And large firms also have greater market power and positional advantages than their smaller rivals, thereby making it easier for large companies to influence the industries they compete in (Leiblein *et al.*, 2002). Intel's dominant role in the semiconductor industry and its corresponding market clout effectively allowed Intel to forge ahead with its planned transition to organic/C4 packaging even though Kobe Semiconductor, a very large supplier of packaging to Intel for decades, preferred not to invest in the new technology.

By stark contrast, smaller firms like Domino Printing or Twister BV necessarily have to consider the short-term cash flow consequences of almost every outsourcing decision they make. As Downs & Mohr (1976) suggest, smaller companies may be particularly disadvantaged in the pursuit of radical innovations because these kinds of R&D forays are frequently not based on existing equipment and infrastructure, and can therefore be more expensive than more modest types of technology jumps. Neither Domino nor Twister had enough money or personnel to internally pursue radical innovations in a concerted and focused way. Both companies effectively had no choice but to solicit outside organizations for these kinds of developments.

But the size of a firm—characterized in both the UK and international surveys by the "Number of Employees" variable—might not make an equal impact in every type of environment. While firm size appears to be a relatively decent predictor of success for business units in fast clockspeed industries in the UK survey sample, this does not seem to be the case for respondents in medium or slow clockspeed industries. There is considerable evidence to suggest that larger firms are a more fruitful environment for the development of new technologies (Chesbrough & Teece, 1996; Hayes & Abernathy, 1980; Kumpe & Bolwijn, 1988), but these prior investigations neglect to explore when and under what circumstances these types of results are best achieved. The findings from the UK survey suggest that firm size might contribute to the R&D process—but not in every type of industry. Medium and slow clockspeed firms appear to be much less affected by this particular environmental factor.

And new research is emerging which suggests that ambitious R&D projects and radical innovation need not be the exclusive domain of large companies. Several small- and medium-sized enterprises (SMEs) have successfully used "learning networks" to leverage their internal expertise. Bessant & Francis (1999) define a learning network as "a network formally set up for the primary purpose of increasing knowledge, expressed as increased capacity to do something" (p. 377). While learning can and does occur spontaneously within informal networks of companies, there is evidence that "purposive structures and mechanisms built around formal learning networks can accelerate the process" (Bessant & Francis, 1999, p. 378). Consequently, a growing number of these kinds of organizations have already been used to help companies overcome the resource limitations that SMEs commonly face when trying to bring about technological change.

8.4 Recommendations for Future Research

One particularly interesting outcome from the statistical analysis of the UK sample was that all of the statistically significant Spearman ρ correlations for fast clockspeed firms were positive. All of the correlations for the medium clockspeed sample, by contrast, were negative. Correlations from the slow clockspeed group were both positive and negative. Overall, the number of significantly related variables in the UK sample was so small that it was difficult to distill any kind of meaningful trend or pattern from these relationships. But the implications of such a pattern would be interesting if it could be more solidly established. These trends might suggest, for example, that fast clockspeed firms perform better in the long-term when they maintain relationships with their existing suppliers in the face of a potentially radical new technology—but medium clockspeed firms would perform better by doing exactly the opposite. Another study based on a larger or more focused sample population might go some way towards offering a higher degree of resolution that might more compellingly and forcefully address this point.

Subsequent work in this area could also attempt to strengthen the research design used in this thesis. A major weakness of the methodology applied in this investigation is its failure to guarantee that every technology jump put forth by the respondents was truly "radical" according to a common definition. As noted earlier, the technology management literature applies a broad range of meanings to this label, and it therefore stands to reason that there is also room for misunderstanding and disagreement on this point among managers in the marketplace. Afuah (2001) solves this problem by selecting a single fast clockspeed technology jump, and by then observing the success or failure of firms in the industry before and after the transition. This methodological approach readily lends itself to establishing a single, consistent definition of radical innovation, thereby eliminating all confusion about this most fundamental building block. Any future research in this area should therefore begin by zooming in on specific radical technology jumps in medium and slow clockspeed industries. Because of the number and profile of the firms involved, the transition from drum brakes to disc brakes in the automotive industry is one potentially fruitful example.

Future research designs could also be tightened by more rigorously defining what a "principal supplier" is. The survey questions were put together to learn about relationships with principal suppliers that contribute significantly to the customer firm's competitive advantage. But the survey instrument used in this investigation essentially left this definition open-ended, and relied on the judgment of individual respondents to decide whether or not a supplier should be classified as "principal." However, a responding manager may have gauged his firm's supplier relationships on a purely economic level, and may therefore have considered vendors that specialize in commodity items that offer very little competitive advantage. Such an interpretation would almost certainly distort the results of this thesis, and future research designs in this area would do well to control this variable more diligently.

A different system for categorizing clockspeeds might also improve the resolving power of this methodology. While Fine (1998) recommends segmenting the industrial spectrum into three categories—fast, medium, and slow—this approach might obscure meaningful differences. In many instances, firms with relatively similar rates of evolution for product technologies were classified in different clockspeed categories because of the boundary definitions outlined in Table 3.1. In light of the fact that the respondents provided estimates to answer this question, however, one wonders how different these companies are in practice. Similar research in the future would probably be more compelling and statistically significant if the data were separated into two groups: fast and slow.

Also, despite the fact that perception-based scales have been used extensively in management research (e.g. Brouthers & Xu, 2002; Delaney & Huselid, 1996; Hunton *et al.*, 2002), there are some obvious limitations to this methodological tool. There can be little doubt that executives and decision-makers "do make mistakes and perceive the same phenomena differently" (Powell, 1996, p. 326). Future investigations in this area should therefore consider gauging success with "hard" measurements or financial indicators that are published and widely agreed upon. Chapter 3 noted that financial results from business units in publicly traded companies are usually aggregated with those of other units within the firm, thereby complicating the job of finding any kind of hard indicator of success at the business unit level. Nonetheless, subsequent research projects would probably benefit from the use of objective measures of performance.

While the issue of how to answer the original research questions leaves ample scope for future work, subsequent investigations in this area might also pay attention to how these questions are asked. The analysis throughout this thesis exactly mirrored the way in which components and activities were decomposed by the companies responsible for each of the make-buy decisions. For example, this study regarded Intel's decision to outsource the production of its packaging units as a discrete judgment because that was how Intel's managers perceived the situation. However, future research in this area might scrutinize more closely the way in which these make-buy decisions are decomposed. Are there instances in which a single make-buy decision should be broken down into a handful of smaller ones? And under what circumstances would it be prudent to fuse several small outsourcing judgments into one decision, thereby delegating all of those activities to a single supplier? This thesis set out to offer insights into how make-buy decisions are resolved in the face of radical innovations, but it did little to reveal how the questions behind such decisions are defined.

Subsequent investigations in this area could also use an entirely different lens to examine the lack of convergence within the technology management literature. This thesis set out to determine whether or not supplier relationships and industry clockspeed are factors that should be added to the existing system of categorization that is applied to make-buy decisions for radical innovations. However, both the survey data and the case studies suggest that they are not. The system of classification therefore remains incomplete, and the elusive variables that would explain this lack of agreement in the literature are still at large.

But the literature offers a few clues as to what these variables might be. As noted in Chapter 2, companies' outsourcing policies very often evolve via a fairly flexible, tacit decision-making process rather than by any kind of explicit methodology (Baines *et al.*, 1999; Mills *et al.*, 1994; Venkatesan, 1992). Alexander & Young (1996) suggest that as few as one third of companies in the UK have any kind of explicit outsourcing strategy in place. This observation is supported by the case studies discussed in this thesis. Despite the fact that Intel is the seventh largest company in the world in terms of market value (Wall Street Journal Europe, 2003), the company does not adhere to any kind of explicit make-buy policy. Instead, managers use Intel's corporate "Mission, Objectives, and Values" guidelines as a vague framework for outsourcing decisions. The specific criteria and strategic considerations behind a specific judgment are, however, left to the discretion of individual managers.

Shell International Exploration and Production, a company visited in the first phase of case studies, has a similarly unstructured approach to outsourcing decisions. "We are a people-centric company," said one Shell manager.[58] "People make the decisions as opposed to judgments being handed down by way of rigid procedures. There is a lot of freedom for project teams to arrive at

[58] Christiaan Luca, Advisor for External Focus of Shell International Exploration and Production in Rijswijk, The Netherlands. Personal communication with author, 10 April 2002.

the best solutions for any particular context, and managers don't consult any kind of make-buy manual," he added.

This thesis approached the problem of make-buy decisions for potentially radical innovations from a relatively macroscopic point of view. The success or failure of a particular outsourcing strategy was implicitly assumed to be attributable to large-scale factors such as the clockspeed of an industry or the longevity of relationships between firms. However, the above evidence suggests that make-buy decisions are strongly influenced by individual people. Outsourcing decisions may therefore succeed or fail not because of any kind of longstanding corporate policy or historical relationship between companies, but because of linkages and trust between managers and personnel within those companies. It follows, therefore, that a valuable contribution could be made in this area by focusing on the role of relationships at the level of individual managers and employees instead of firms.

REFERENCES

Abernathy, W. J., & Clark, K. B. (1985). Innovation: Mapping the Winds of Creative Destruction. *Research Policy, 14* (1), 3-22.

Afuah, A. (1998). *Innovation Management: Strategies, Implementation, and Profits*. New York: Oxford University Press.

Afuah, A. (2000). How Much Do Your Co-opetitors' Capabilities Matter in the Face of Change? *Strategic Management Journal, 21* (3), 387-404.

Afuah, A. (2001). Dynamic Boundaries of the Firm: Are Firms Better Off Being Vertically Integrated in the Face of a Technological Change? *Academy of Management Journal, 44* (6), 1211-1228.

Akkermans, H., Meijboom, B., & Voordijk, H. (2003). *Supply Chain Co-ordination and Industry Clockspeed: An Exploratory Study.* Paper presented at the EurOMA-POMS Conference, June 16-18, Lake Como, Italy. In Vol. 2 of proceedings, pp. 3-12.

Alexander, M., & Young, D. (1996). Strategic Outsourcing. *Long Range Planning, 29* (1), 116-119.

Allen, T. J., & Cohen, S. I. (1969). Information Flow in Research and Development Laboratories. *Administrative Science Quarterly, 14* (1), 12-19.

Anderson, E., & Weitz, B. A. (1986). Make-or-Buy Decisions: Vertical Integration and Marketing Productivity. *Sloan Management Review, 27* (Spring), 3-19.

Arora, A., & Gambardella, A. (1997). Domestic Markets and International Competitiveness: Generic and Product-Specific Competencies in the Engineering Sector. *Strategic Management Journal, 18* (Summer Special Issue), 53-74.

Audi, R. (1999). *The Cambridge Dictionary of Philosophy* (2nd ed.). Cambridge, United Kingdom: Cambridge University Press.

Baines, T. S., Whitney, D. E., & Fine, C. (1999). Manufacturing Technology Sourcing Practices in the USA. *International Journal of Production Research, 37* (4), 939-956.

Balakrishnan, S., & Wernerfelt, B. (1986). Technical Change, Competition and Vertical Integration. *Strategic Management Journal, 7* (4), 347-359.

Barney, J. B. (1999). How a Firm's Capabilities Affect Boundary Decisions. *Sloan Management Review, 40* (Spring), 137-145.

Bartlett, C. A., & Ghoshal, S. (2002). Building Competitive Advantage Through People. *MIT Sloan Management Review, 43* (Winter), 34-41.

Bessant, J., & Francis, D. (1999). Using Learning Networks to Help Improve Manufacturing Competitiveness. *Technovation, 19* (6/7), 373-381.

Bessant, J., Kaplinsky, R., & Lamming, R. (2003). Putting Supply Chain Learning into Practice. *International Journal of Operations & Production Management, 23* (2), 167-184.

Bessant, J., & Tsekouras, G. (2001). Developing Learning Networks. *AI & Society, 15* (1/2), 82-98.

Bolton, M. K. (1993). Organizational Innovation and Substandard Performance: When Is Necessity the Mother of Innovation? *Organization Science, 4* (1), 57-75.

Bozdogan, K., Deyst, J., Hoult, D., & Lucas, M. (1998). Architectural Innovation in Product Development Through Early Supplier Integration. *R&D Management, 28* (3), 163-173.

Brouthers, L. E., & Xu, K. (2002). Product Stereotypes, Strategy and Performance Satisfaction: The Case of Chinese Exporters. *Journal of International Business Studies, 33* (4), 657-677.

Bukchin, J. (1998). A Comparative Study of Performance Measures for Throughput of a Mixed Model Assembly Line in a JIT Environment. *International Journal of Production Research, 36* (10), 2669-2685.

Campbell, J. M. (1998). *Gas Conditioning and Processing* (7th ed. Vol. 1). Norman, Oklahoma: Campbell Petroleum Services.

Cáñez, L. (2000). *Industrial Make-or-Buy Decisions: Developing a Framework and a Practical Process.* Unpublished PhD thesis, University of Cambridge, Cambridge, United Kingdom.

Cáñez, L., & Probert, D. R. (1999). *Technology Sourcing: The Link to Make-or-Buy.* Paper presented at the Portland International Conference on Management of Engineering and Technology (PICMET), Portland, Oregon. In Vol. 1 of proceedings, p. 3.

Chesbrough, H. W. (2003). The Era of Open Innovation. *MIT Sloan Management Review, 44* (Spring), 35-41.

Chesbrough, H. W., & Teece, D. J. (1996). When Is Virtual Virtuous? Organizing for Innovation. *Harvard Business Review, 74* (January-February), 65-73.

Christensen, C. M. (1997). *The Innovator's Dilemma*. Boston, Massachusetts: Harvard Business School Press.

Christensen, C. M. (2002). The Rules of Innovation. *Technology Review, 105* (June), 33-38.

Christensen, C. M., & Raynor, M. E. (2003). *The Innovator's Solution: Creating and Sustaining Successful Growth*. Boston, Massachusetts: Harvard Business School Press.

Christensen, C. M., Suárez, F. F., & Utterback, J. M. (1998). Strategies for Survival in Fast-Changing Industries. *Management Science, 44* (12), S207-S220.

Christensen, C. M., & Sundahl, D. (2001). *The Process of Building Theory* (Working Paper # 02-016). Boston: Harvard Business School.

Christensen, C. M., Verlinden, M., & Westerman, G. (2001). *Disruption, Disintegration, and the Dissipation of Differentiability* (Working Paper # 00-074). Boston: Harvard Business School.

Coase, R. (1937). The Nature of the Firm. *Economica (New Series), 4* (16), 386-405.

Collins, J. C., & Porras, J. I. (1996). *Built to Last: Successful Habits of Visionary Companies*. London: Century, Ltd.

Conn, C., & White, D. (1994). The Revolution in Upstream Oil and Gas. *The McKinsey Quarterly,* Issue 3, 71-86.

Cooper, A. C., & Schendel, D. (1976). Strategic Responses to Technological Threats. *Business Horizons, 19* (1), 61-69.

Cooper, D. R., & Emory, C. W. (1995). *Business Research Methods* (5th ed.). Chicago: Irwin.

Day, G. S., & Schoemaker, P. J. H. (2000). Chapter 1: A Different Game. In G. S. Day, P. J. H. Schoemaker & R. E. Gunther (Eds.), *Wharton on Managing Emerging Technologies* (pp. 1-23). New York: John Wiley & Sons, Inc.

Delaney, J. T., & Huselid, M. A. (1996). The Impact of Human Resource Management Practices on Perceptions of Organizational Performance. *Academy of Management Journal, 39* (4), 949-969.

Dillman, D. A. (1978). *Mail and Telephone Surveys: The Total Design Method*. New York: John Wiley & Sons.

Dillman, D. A. (2000). *Mail and Internet Surveys: The Tailored Design Method* (2nd ed.). New York: John Wiley & Sons, Inc.

Doig, S. J., Ritter, R. C., Speckhals, K., & Woolson, D. (2001). Has Outsourcing Gone Too Far? *The McKinsey Quarterly,* Issue 4, 25-37.

Dowling, M., & Cheang, C. T. (2000). Shifting Comparative Advantage in Asia: New Tests of the "Flying Geese" Model. *Journal of Asian Economics, 11* (4), 443-463.

Downs, G. W., & Mohr, L. B. (1976). Conceptual Issues in the Study of Innovation. *Administrative Science Quarterly, 21* (4), 700-714.

Doz, Y., & Hamel, G. (1997). The Use of Alliances in Implementing Technology Strategies. In M. L. Tushman & P. Anderson (Eds.), *Managing Strategic Innovation and Change* (pp. 556-580). New York: Oxford University Press.

Dyer, J. H. (1996). How Chrysler Created an American Keiretsu. *Harvard Business Review, 74* (July-August), 42-56.

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review, 14* (4), 532-550.

Eisenhardt, K. M., & Schoonhoven, C. B. (1996). Resource-based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms. *Organization Science, 7* (2), 136-150.

Epstein, J. M., & Axtell, R. (1996). *Growing Artificial Societies: Social Science from the Bottom Up*. Cambridge, Massachusetts: MIT Press.

Ernst, D., & Steinhubl, A. M. J. (1997). Alliances in Upstream Oil and Gas. *The McKinsey Quarterly,* Issue 2, 144-155.

Esposito, E., & Raffa, M. (2001). Surviving a Crisis? Make or Buy Decisions in Innovative Industries and Their Effects on Supply Chain. *Enterprise and Innovation Management Studies, 2* (3), 161-176.

Evans, P., & Wurster, T. S. (2000). *Blown to Bits: How the New Economics of Information Transforms Strategy*. Boston, Massachusetts: Harvard Business School Press.

Fine, C. H. (1998). *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. Reading, Massachusetts: Perseus Books.

Fine, C. H., Vardan, R., Pethick, R., & El-Hout, J. (2002). Rapid-Response Capability in Value-Chain Design. *Sloan Management Review, 43* (Winter), 69-75.

Fine, C. H., & Whitney, D. E. (1996). *Is the Make-Buy Decision Process a Core Competence?* (Working Paper # 3875-96). Cambridge, Massachusetts: MIT Center for Technology, Policy, and Industrial Development.

Fischer, F. (1998). Beyond Empiricism: Policy Inquiry in Postpositivist Perspective. *Policy Studies Journal, 26* (1), 129-146.

Fisher, J. G. (1998). Contingency Theory, Management Control Systems and Firm Outcomes: Past Results and Future Directions. *Behavioral Research in Accounting, 10* (Supplemental), 47-64.

Flick, U. (1998). *An Introduction to Qualitative Research*. London: Sage Publications.

Forza, C. (2002). Survey Research in Operations Management: A Process-Based Perspective. *International Journal of Operations & Production Management, 22* (2), 152-194.

Foster, J. (2000). Is There a Role for Transaction Cost Economics If We View Firms as Complex Adaptive Systems? *Contemporary Economic Policy, 18* (4), 369-385.

Galford, R., & Drapeau, A. S. (2003). The Enemies of Trust. *Harvard Business Review, 81* (February), 88-95.

Gates, B. (1996). *The Road Ahead* (Revised ed.). London: Penguin Books.

Gawer, A., & Cusumano, M. A. (2002). *Platform Leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*. Boston, Massachusetts: Harvard Business School Press.

Gertner, R., & Knez, M. J. (2000). Vertical Integration: Make or Buy Decisions. In T. Dickson (Ed.), *Mastering Strategy* (pp. 146-151). Harlow, United Kingdom: Pearson Education Limited.

Gietzmann, M. B. (1995). Make or Buy Revisited: Some Lessons from Japan. *Management Accounting: Magazine for Chartered Management Accountants, 73* (1), 24-25.

Gilbert, C. (2003). The Disruption Opportunity. *MIT Sloan Management Review, 44* (Summer), 27-32.

Glasmeier, A. (1997). Technological Discontinuities and Flexible Production Networks: The Case of Switzerland and the World Watch Industry. In M. L. Tushman & P. Anderson (Eds.), *Managing Strategic Innovation and Change: A Collection of Readings* (pp. 24-42). New York: Oxford University Press.

Grossman, G. M., & Helpman, E. (2001). *Outsourcing in a Global Economy* (Working Paper). Princeton, New Jersey: Princeton University/Tel Aviv University.

Guba, E. G. (1990). The Alternative Paradigm Dialog. In E. G. Guba (Ed.), *The Paradigm Dialog* (pp. 17-30). Newbury Park, California: Sage Publications.

Handfield, R. B., & Melnyk, S. A. (1998). The Scientific Theory-building Process: A Primer Using the Case of TQM. *Journal of Operations Management, 16* (4), 321-339.

Hardy, C., Phillips, N., & Lawrence, T. (1998). Distinguishing Trust and Power in Interorganizational Relations: Forms and Façades of Trust. In C. Lane & R. Bachmann (Eds.), *Trust Within and Between Organizations: Conceptual Issues and Empirical Applications* (pp. 64-87). Oxford: Oxford University Press.

Harrigan, K. R. (1984). Formulating Vertical Integration Strategies. *Academy of Management Review, 9* (4), 638-652.

Hawawini, G., Subramanian, V., & Verdin, P. (2000). *Is Profitability Driven by Industry- or Firm-Specific Factors? A New Look at the Evidence* (Working Paper # 2000/80/FIN). Fontainebleau, France: INSEAD.

Hayes, R. H., & Abernathy, W. J. (1980). Managing Our Way to Economic Decline. *Harvard Business Review, 58* (July-August), 67-77.

Henderson, R., & Mitchell, W. (1997). The Interactions of Organizational and Competitive Influences on Strategy and Performance. *Strategic Management Journal, 18* (Summer Special Issue), 5-14.

Henderson, R. M., & Clark, K. B. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly, 35* (1), 9-30.

Herbert, L., & Perrons, R. (2000). Using "Shadow Prices" as a Tool for Grassroots Environmental Assessment of Air Emissions. *Shell Exploration and Production Newsletter,* May issue, 41-43.

Hill, C. W. L., & Rothaermel, F. T. (2003). The Performance of Incumbent Firms in the Face of Radical Technological Innovation. *Academy of Management Review, 28* (2), 257-274.

Hilliard, R. (2003). Profile: Erik Vollebregt. *Changes: Shell International Exploration and Production BV's External Magazine, 4* (1)*,* 28-30.

Hoecht, A., & Trott, P. (1999). Trust Risk and Control in the Management of Collaborative Technology Development. *International Journal of Innovation Management, 3* (3), 257-270.

Holton, G., Chang, H., & Jurkowitz, E. (1996). How a Scientific Discovery is Made: A Case History. *American Scientist, 84* (4), 364-376.

Honderich, T. (1995). *The Oxford Companion to Philosophy*. New York: Oxford University Press.

Hoyos, C. (2004). February 5, "Investors Push for Changes at Shell". *The Financial Times (UK edition),* p. 19.

Hunton, J. E., McEwen, R. A., & Wier, B. (2002). The Reaction of Financial Analysts to Enterprise Resource Planning (ERP) Implementation Plans. *Journal of Information Systems, 16* (1), 31-40.

Jick, T. D. (1979). Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly, 24* (4), 602-611.

Kern, T., & Blois, K. (2002). Norm Development in Outsourcing Relationships. *Journal of Information Technology, 17* (1), 33-42.

King, G., Keohane, R. O., & Verba, S. (1994). *Designing Social Inquiry: Scientific Inference in Qualitative Research*. Princeton, New Jersey: Princeton University Press.

Kolb, D. A., Rubin, I. M., & McIntyre, J. M. (1979). *Organizational Psychology: An Experiential Approach* (3rd ed.). Englewood Cliffs, New Jersey: Prentice-Hall.

Kumar, N. (1996). The Power of Trust in Manufacturer-Retailer Relationships. *Harvard Business Review, 74* (November-December), 92-106.

Kumpe, T., & Bolwijn, P. T. (1988). Manufacturing: The New Case for Vertical Integration. *Harvard Business Review, 66* (March-April), 75-81.

Lacity, M. C., & Hirschheim, R. (1993). *Information Systems Outsourcing*. New York: John Wiley & Sons.

LaPiere, R. T. (1934). Attitudes vs. Actions. *Social Forces, 13* (2), 230-237.

Lee, K. S. (2000). *Production Cost, Transaction Cost, and Outsourcing Strategy: A Game Theoretic Analysis* (Working Paper RPS #2000-021—MKT). Singapore: National University of Singapore.

Leiblein, M. J., Reuer, J. J., & Dalsace, F. (2002). Do Make or Buy Decisions Matter? The Influence of Organizational Governance on Technological Performance. *Strategic Management Journal, 23* (9), 817-833.

Leifer, R., McDermott, C. M., Colarelli O'Connor, G., Peters, L. S., Rice, M., & Veryzer, R. W. (2000). *Radical Innovation: How Mature Companies Can Outsmart Upstarts*. Boston, Massachusetts: Harvard Business School Press.

Leonard-Barton, D. (1995). *Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation*. Boston: Harvard Business School Press.

Levin, R. I. (1987). *Statistics for Management*. Englewood Cliffs, New Jersey: Prentice-Hall.

Litwin, M. S. (1995). *How to Measure Survey Reliability and Validity*. Thousand Oaks, California: Sage Publications.

Loudon, A. (2001). *Webs of Innovation*. Harlow, UK: Pearson Education Limited.

Macbeth, D. K., & Chan, K. C. (1994). *World Class Manufacturing Through Relationship Management.* Paper presented at the First International Conference of the European Operations Management Association (EOMA), Cambridge, United Kingdom. In Vol. 1 of proceedings, pp. 19-24.

Mahajan, R., Brown, K., & Atluri, V. (2000). The Evolution of Microprocessor Packaging. *Intel Technology Journal, 4* (3), 1-10.

Manders, A. J. C., & Brenner, Y. S. (1995). "Make or Buy": The Potential Subversion of Corporate Strategy—The Case of Philips. *International Journal of Social Economics, 22* (4), 4-11.

McCloskey, D. N. (1985). *The Rhetoric of Economics*. Madison, Wisconsin: University of Wisconsin Press.

McDermott, C. M. (1999). Managing Radical Product Development in Large Manufacturing Firms: A Longitudinal Study. *Journal of Operations Management, 17* (6), 631-644.

McGahan, A. M., & Porter, M. E. (1997). How Much Does Industry Matter, Really? *Strategic Management Journal, 18* (Summer Special Issue), 15-30.

McIvor, R. T., & Humphreys, P. K. (2000). A Case-based Reasoning Approach to the Make or Buy Decision. *Integrated Manufacturing Systems, 11* (5), 295-310.

Meredith, J. (1998). Building Operations Management Theory through Case and Field Research. *Journal of Operations Management, 16* (4), 441-454.

Miles, M. B. (1979). Qualitative Data as an Attractive Nuisance: The Problem of Analysis. *Administrative Science Quarterly, 24* (4), 590-601.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook* (2nd ed.). Thousand Oaks, California: Sage Publications.

Mills, J., Neely, A., Platts, K., Gregory, M., & Richards, H. (1994). *Strategy Evolution: Incorporating Time in the Manufacturing Strategy Process.* Paper presented at the First International Conference of the European Operations Management Association (EOMA), Cambridge, United Kingdom. In proceedings, pp. 235-240.

Mingers, J., & Brocklesby, J. (1997). Multimethodology: Towards a Framework for Mixing Methodologies. *Omega—The International Journal of Management Science, 25* (5), 489-509.

Minshall, T. (1999). A Resource-based View of Alliances: The Case of the Handheld Computer Industry. *International Journal of Innovation Management, 3* (2), 159-183.

Mintzberg, H. (1979). An Emerging Strategy of "Direct" Research. *Administrative Science Quarterly, 24* (4), 580-589.

Monteverde, K., & Teece, D. J. (1982). Supplier Switching Costs and Vertical Integration in the Automobile Industry. *Bell Journal of Economics, 13* (1), 206-213.

Neumayer, E. (2002). Do We Trust the Data? On the Validity and Reliability of Cross-National Environmental Surveys. *Social Science Quarterly, 83* (1), 332-340.

Nicholls-Nixon, C. L., & Woo, C. Y. (2003). Technology Sourcing and Output of Established Firms in a Regime of Encompassing Technological Change. *Strategic Management Journal, 24* (7), 651-666.

Novak, S., & Eppinger, S. D. (2001). Sourcing by Design: Product Complexity and the Supply Chain. *Management Science, 47* (1), 189-204.

Okimoto, F., & Brouwer, J. M. (2002). Supersonic Gas Conditioning. *World Oil, 223* (8)*,* 89-91.

Oppenheim, A. N. (1992). *Questionnaire Design, Interviewing and Attitude Measurement*. London: Pinter Publishers.

Pavitt, K. (1990). What We Know about the Strategic Management of Technology. *California Management Review, 32* (3), 17-26.

Penrose, E. T. (1980). *The Theory of the Growth of the Firm* (2nd ed.). Oxford: Basil Blackwell.

Perrons, R. K. (1997). *Make-Buy Decisions in the US Aircraft Industry.* Unpublished Master of Science (SM) thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Perrons, R. K. (2004). Intel's Flyosaurus. *IEE Manufacturing Engineer* (April/May)*,* 14-15.

Piachaud, B. S. (2000). *Investigating the Costs and Benefits of Outsourcing to Clinical Research: Perceptions from the Pharmaceutical Industry* (Working Paper RP # ABS/2000/007). Aberdeen, United Kingdom: The Robert Gordon University.

Pindyck, R. S., & Rubinfeld, D. L. (1995). *Microeconomics* (3rd ed.). Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Platts, K. W. (1993). A Process Approach to Researching Manufacturing Strategy. *International Journal of Operations & Production Management, 13* (8), 4-17.

Porter, M. E. (1980). *Competitive Strategy*. New York: The Free Press.

Porter, M. E. (1985). *Competitive Advantage*. New York: The Free Press.

Porter, M. E. (1990). *The Competitive Advantage of Nations*. New York: The Free Press.

Porter, M. E. (1991). Towards a Dynamic Theory of Strategy. *Strategic Management Journal, 12* (8), 95-117.

Powell, T. C. (1996). How Much Does Industry Matter? An Alternative Empirical Test. *Strategic Management Journal, 17* (4), 323-334.

Prahalad, C. K., & Hamel, G. (1990). The Core Competence of the Corporation. *Harvard Business Review, 68* (May-June), 79-91.

Primo, M. A. M., & Amundson, S. D. (2002). An Exploratory Study of the Effects of Supplier Relationships on New Product Development Outcomes. *Journal of Operations Management, 20* (1), 33-52.

Probert, D. R. (1996). The Practical Development of a Make or Buy Strategy: The Issue of Process Positioning. *Integrated Manufacturing Systems, 7* (2), 44-51.

Probert, D. R., Cáñez, L., & Platts, K. W. (2001). *Technology Transfer and Succession Planning: The Relevance of Make-or-Buy Analysis.* Paper presented at the Portland International Conference on Management of Engineering and Technology (PICMET), Portland, Oregon. In Vol. 3 ("Technology Management in the Knowledge Era") of proceedings, pp. 439-443.

Probert, D. R., Jones, S. W., & Gregory, M. J. (1993). The Make or Buy Decision in the Context of Manufacturing Strategy Development. *Proceedings of the Institution of Mechanical Engineers—Part B: Journal of Engineering Manufacture, 207*, 241-250.

Prusak, L., & Davenport, T. H. (2003). Who Are the Gurus' Gurus? *Harvard Business Review, 81* (December), 14-16.

Quinn, J. B. (1999). Strategic Outsourcing: Leveraging Knowledge Capabilities. *Sloan Management Review, 40* (Summer), 9-21.

Quinn, J. B. (2000). Outsourcing Innovation: The New Engine of Growth. *Sloan Management Review, 41* (Summer), 13-28.

Quinn, J. B., & Hilmer, F. G. (1994). Strategic Outsourcing. *Sloan Management Review, 35* (Summer), 43-55.

Reiss, A. J. (1968). Stuff and Nonsense about Social Surveys and Observation. In H. Becker, B. Geer, D. Riesman & R. Weiss (Eds.), *Institutions and the Person* (pp. 351-367). Chicago: Aldine.

Rigby, D., & Zook, C. (2002). Open-Market Innovation. *Harvard Business Review, 80* (October), 5-12.

Roussel, P. A., Saad, K. N., & Erickson, T. J. (1991). *Third Generation R&D: Managing the Link to Corporate Strategy*. Boston, Massachusetts: Harvard Business School Press.

Rumelt, R. P. (1991). How Much Does Industry Matter? *Strategic Management Journal, 12* (3), 167-185.

Sako, M. (1992). *Prices, Quality, and Trust: Inter-firm Relations in Britain and Japan*. Cambridge, United Kingdom: Cambridge University Press.

Sako, M. (1998). Does Trust Improve Business Performance? In C. Lane & R. Bachmann (Eds.), *Trust Within and Between Organizations: Conceptual Issues and Empirical Applications* (pp. 88-117). Oxford: Oxford University Press.

Schmalensee, R. (1985). Do Markets Differ Much? *The American Economic Review, 75* (3), 341-351.

Schumpeter, J. A. (2000). *Capitalism, Socialism and Democracy* (5th ed.). London: Routledge.

Shenhar, A. J. (2001). One Size Does Not Fit All Projects: Exploring Classical Contingency Domains. *Management Science, 47* (3), 394-414.

Sieber, S. D. (1973). The Integration of Fieldwork and Survey Methods. *The American Journal of Sociology, 78* (6), 1335-1359.

Sutcliffe, K. M., & Weber, K. (2003). The High Cost of Accurate Knowledge. *Harvard Business Review, 81* (May), 74-82.

Swink, M., & Way, M. H. (1995). Manufacturing Strategy: Propositions, Current Research, Renewed Directions. *International Journal of Operations & Production Management, 15* (7), 4-26.

Tamosaitis, W. L., & Schwenker, M. G. (2002). Recruiting and Retaining Technical Personnel at a Contractor-Operated Government Site. *Engineering Management Journal, 14* (1), 29-34.

Tatikonda, M. V., & Rosenthal, S. R. (2000). Technology Novelty, Project Complexity, and Product Development Project Execution Success: A Deeper Look at Task Uncertainty in Product Innovation. *IEEE Transactions on Engineering Management, 47* (1), 74-87.

Teece, D. J. (1992). Competition, Cooperation, and Innovation: Organizational Arrangements for Regimes of Rapid Technological Progress. *Journal of Economic Behavior and Organization, 18* (1), 1-25.

Tidd, J. (1997). Complexity, Networks and Learning: Integrative Themes for Research on Innovation Management. *International Journal of Innovation Management, 1* (1), 1-22.

Tidd, J., Bessant, J., & Pavitt, K. (2001). *Managing Innovation: Integrating Technological, Market, and Organizational Change* (2nd ed.). Chichester, UK: John Wiley & Sons Ltd.

Tosi, H. L., & Slocum, J. W. (1984). Contingency Theory: Some Suggested Directions. *Journal of Management, 10* (1), 9-26.

Tristram, C. (2003). Reinventing the Transistor. *Technology Review, 106* (7), 54-62.

Tushman, M. L., & Anderson, P. (1986). Technological Discontinuities and Organizational Environments. *Administrative Science Quarterly, 31* (3), 439-465.

Ulrich, K. (1995). The Role of Product Architecture in the Manufacturing Firm. *Research Policy, 24* (3), 419-440.

Utterback, J. M. (1994). *Mastering the Dynamics of Innovation*. Boston, Massachusetts: Harvard Business School Press.

Utterback, J. M., & Meyer, M. H. (1993). The Product Family and the Dynamics of Core Capability. *Sloan Management Review, 34* (Spring), 29-47.

Van Maanen, J. (1975). Police Socialization: A Longitudinal Examination of Job Attitudes in an Urban Police Department. *Administrative Science Quarterly, 20* (2), 207-228.

Veloso, F., & Fixson, S. (2001). Make-Buy Decisions in the Auto Industry: New Perspectives on the Role of the Supplier as an Innovator. *Technological Forecasting and Social Change, 67*, 239-257.

Venkatesan, R. (1992). Strategic Sourcing: To Make or Not To Make. *Harvard Business Review, 70* (November-December), 98-107.

Vidich, A. J., & Shapiro, G. (1955). A Comparison of Participant Observation and Survey Data. *American Sociological Review, 20* (1), 28-33.

von Hippel, E. (1988). *The Sources of Innovation*. New York: Oxford University Press.

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case Research in Operations Management. *International Journal of Operations & Production Management, 22* (2), 195-219.

Walker, G., & Weber, D. (1984). A Transaction Cost Approach to Make-or-Buy Decisions. *Administrative Science Quarterly, 29*, 373-391.

Walker, G., & Weber, D. (1987). Supplier Competition, Uncertainty, and Make-or-Buy Decisions. *Academy of Management Journal, 30* (3), 589-596.

Wall Street Journal Europe. (2003). September 26-28, "The Global Giants", p. R6.

Welch, J. A., & Nayak, P. R. (1992). Strategic Sourcing: A Progressive Approach to the Make-or-Buy Decision. *Academy of Management Executive, 6* (1), 23-31.

Wilkinson, I., & Young, L. (2002). On Cooperating Firms, Relations and Networks. *Journal of Business Research, 55* (2), 123-132.

Williamson, O. E. (1981). The Economics of Organization: The Transaction Cost Approach. *American Journal of Sociology, 87* (3), 548-577.

Williamson, O. E. (1993). The Logic of Economic Organization. In O. E. Williamson & S. G. Winter (Eds.), *The Nature of the Firm: Origins, Evolution, and Development* (pp. 90-116). Oxford: Oxford University Press.

Wilson, E. J., & Vlosky, R. P. (1997). Partnering Relationship Activities: Building Theory from Case Study Research. *Journal of Business Research, 39* (1), 59-70.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The Machine that Changed the World*. New York: Rawson Associates.

Yergin, D. (1991). *The Prize: The Epic Quest for Oil, Money, and Power*. New York: Touchstone.

Yin, R. K. (1981). The Case Study Crisis: Some Answers. *Administrative Science Quarterly, 26* (1), 58-65.

Yin, R. K. (1993). *Applications of Case Study Research*. Thousand Oaks, California: Sage Publications.

Yin, R. K. (1994). *Case Study Research: Design and Methods* (2nd ed.). Thousand Oaks, California: Sage Publications.

Yoon, K. P., & Naadimuthu, G. (1994). A Make-or-Buy Decision Analysis Involving Imprecise Data. *International Journal of Operations & Production Management, 14* (2), 62-69.

Young, G. J., Parker, V. A., & Charns, M. P. (2001). Provider Integration and Local Market Conditions: A Contingency Theory Approach. *Health Care Management Review, 26* (2), 73-79.

Zaheer, A., McEvily, B., & Perrone, V. (1998). Does Trust Matter? Exploring the Effects of Interorganizational and Interpersonal Trust on Performance. *Organization Science, 9* (2), 141-159.

APPENDIX A: PHASE ONE SEMI-STRUCTURED INTERVIEW QUESTIONS

QUESTIONS THAT I WANT TO GET ANSWERS TO DURING THE ROUNDTABLE DISCUSSION

UNIVERSITY OF CAMBRIDGE

BY ROB PERRONS
CENTRE FOR STRATEGY & PERFORMANCE

1) Let me start by explicitly defining what I mean by make-buy or outsourcing decisions. They are the decisions to retain the manufacture of a component or a process in-house (a "make" decision), or to give the job to a vendor (a "buy" decision). Can you think of any recent scenario that required such a decision-making process in the last few months or years? Both new and old technology examples would be handy (could include components or processes). Can I get my hands on documents that outline such a decision process, i.e. a memo that outlines why a particular sourcing decision was adopted?

2) What is the general make-buy decision making process within your company for most components or processes that are ***not*** considered new technologies? What factors are taken into consideration?

3) Who in the organization is charged with making these decisions? Where in the organization are they situated (i.e. draw org. chart and point them out)? Is it a well-defined process? Is it captured formally in a flowchart somewhere? Or is this role re-defined on an *ad hoc* basis? And if it is *ad hoc*, do the decisions at least tend to be consistent from one to the next?

4) How does the above situation described in 2) and 3) differ from how you would handle a make-buy decision for a new technology product or process?

5) Discuss the role of trust between you and your suppliers. Does it play a key role in your make-buy decisions? Do you have longstanding supplier relationships, or are most of them quite short and arm's-length? Are you much more likely to outsource something to a supplier that you can trust than to a firm that is new to you?

6) What role do suppliers play in your company's innovation process? Can you think of any new technologies that you brought on-board with the help of a supplier?

7) When you make the transition from one technology to the next, do you tend to switch suppliers or do you hang on to the old ones, but work with them to "bring them up to speed" with the new technologies? Is this equally true for radical and for incremental technologies?

8) Please give an example of a situation in which you dumped a supplier because of a switch to a new technology.

9) Please give an example of a situation where you stayed with an existing supplier, and worked with them to adopt a new technology.

10) How much time and effort does it take to build a trust-based relationship with a supplier? What are the advantages of having such a relationship?

11) How does your company collect competitive data about other firms in the industry? How do you assess your strengths, weaknesses, etc. in the industry vis-à-vis everyone else?

12) How does your firm balance the various facets—cost, strategic concerns, etc.—that have to be weighed against one another throughout the outsourcing decision process?

13) Are the decisions typically static and final, or do you re-visit them periodically to make sure that things are moving in the right direction?

14) When making the transition to a new technology, are you more prone than normal to in-source parts and processes that involve the new technology? Why is that? And would you expect to outsource the job to a vendor later on when the technology is less novel?

15) Have you as a company ever positioned yourself strategically in such a way that you were trying to make sure that you could never be supplanted in the marketplace by a vendor? That is, do you consider any of your vendors to be a threat to your firm's position with respect to a particular process or component? Why or why not? And if so, what steps have you ever taken to make sure that they couldn't wrestle market power away from you?

16) Have you ever perceived a customer—that is, someone downstream of your organization—to be a potential strategic threat that you ought to worry about? Was a make-buy decision ever influenced by this perception?

APPENDIX B: SURVEY INSTRUMENT

SURVEY OF SUPPLIERS' LONG-TERM ROLE IN NEW TECHNOLOGY DEVELOPMENT AND ADOPTION

UNIVERSITY OF CAMBRIDGE

CENTRE FOR STRATEGY & PERFORMANCE

March 2003

Survey serial number (strictly for tracking purposes) ____________________

Protection of Data Confidentiality

All the data that you provide to the University of Cambridge that are otherwise not publicly available will not be released in any way that would compromise the confidentiality of the survey. No information you provide, even if you do not consider it proprietary or confidential, shall be presented or published in a way that would permit the identification of any individual respondent or any individual company without your company's prior written permission.

SURVEY OVERVIEW AND INSTRUCTIONS

This survey is intended to measure how different business units develop relationships with their suppliers in the face of competence-destroying technologies, and to determine if some types of relationships yield better results in the long-term. It asks questions about your perception of various aspects of your business unit and how it is managed. Inasmuch as the survey consists of only 21 questions, it should not take a lot of time to complete.

While completing this survey, please provide responses to all questions at the industry business unit level rather than at the company, program, or project level. For the purposes of this survey, an ***individual business unit*** is defined as an organization that produces a particular line of products (as opposed to a corporation that might consist of multiple business units or companies that might produce a broad range of products).

All data will be held in the strictest confidence, and all results will be reported in aggregated form so that no single respondent will be identifiable from the findings.

If you have any questions about the survey, please feel free to contact me at the address below. ***Please return your completed survey in the enclosed FREEPOST envelope by 8 April 2003 to***:

Rob Perrons
Institute for Manufacturing
FREEPOST NATE599
Mill Lane
Cambridge
CB2 1BR

office phone: (01223)-338-192
fax: (01223)-338-076
e-mail: rkp22@cam.ac.uk

Many thanks for your help!

1.0 WHAT KIND OF COMPANY/INDUSTRY DO YOU WORK IN?

1.1 On average, how frequently does your business unit introduce significant new product technologies?

__________________ years

1.2 On average, how frequently does your business unit significantly change its organizational structures?

__________________ years

1.3 On average, how frequently does your business unit introduce significant new process technologies?

__________________ years

1.4 Approximately how many employees does your business unit have?

__________________ employees

1.5 What ***competence-destroying technological leaps*** has your business unit experienced throughout its life?

A competence-destroying technology typically shifts the fundamental skills and knowledge base of an industry. It often results in the introduction of new firms and fundamentally new product architectures and standards in the market. The leap from typewriters to word processors is one example of this kind of shift, as is the move to DVDs from videocassettes.

Please describe the technological leaps in the chart below, providing the approximate dates when they occurred.

Example:

	Shifted From	Shifted To	Approximate Date
1	Videocassette recording media	DVD digital recording media	1997

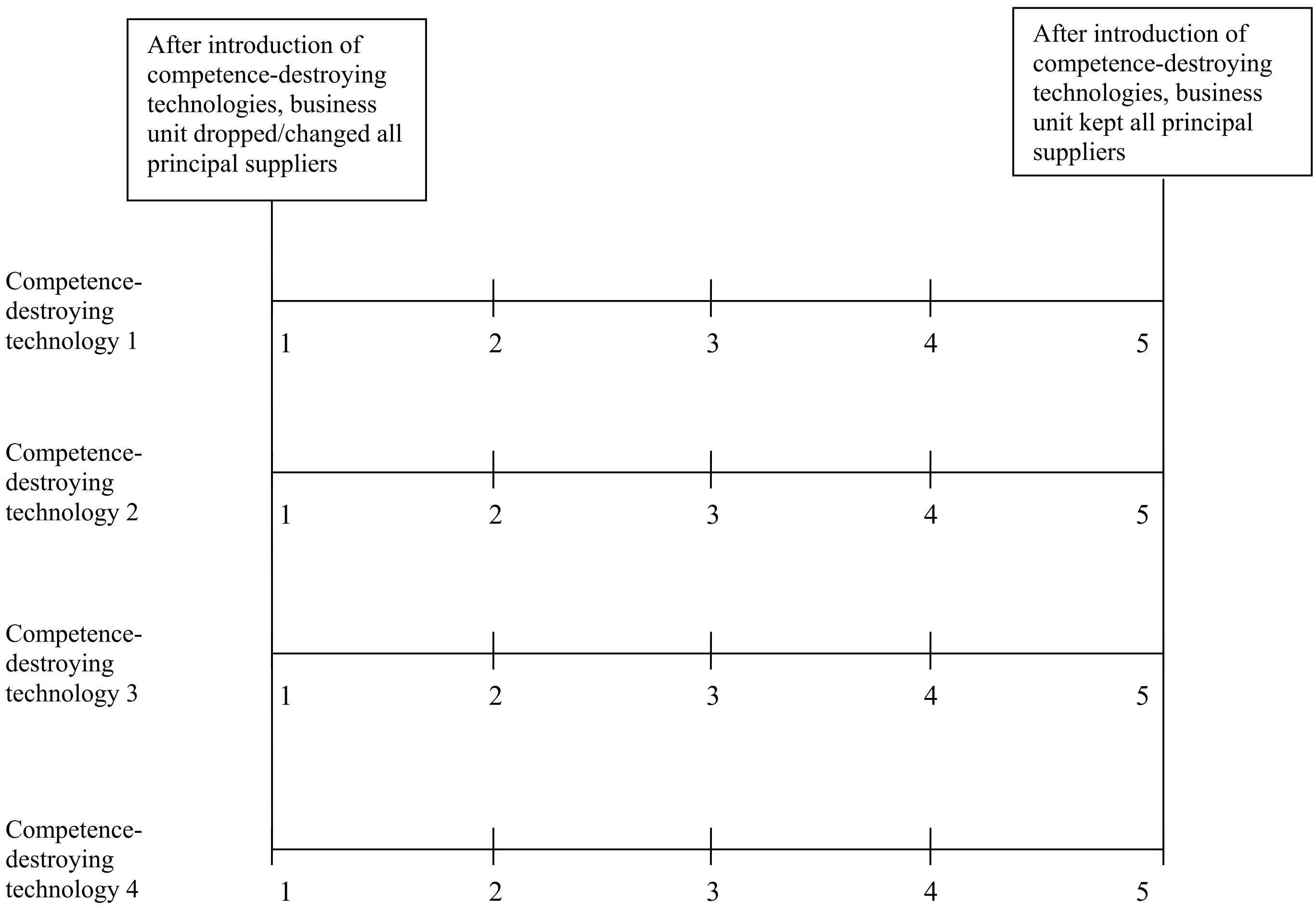
Your Response:

	Shifted From	Shifted To	Approximate Date
1			
2			
3			
4			

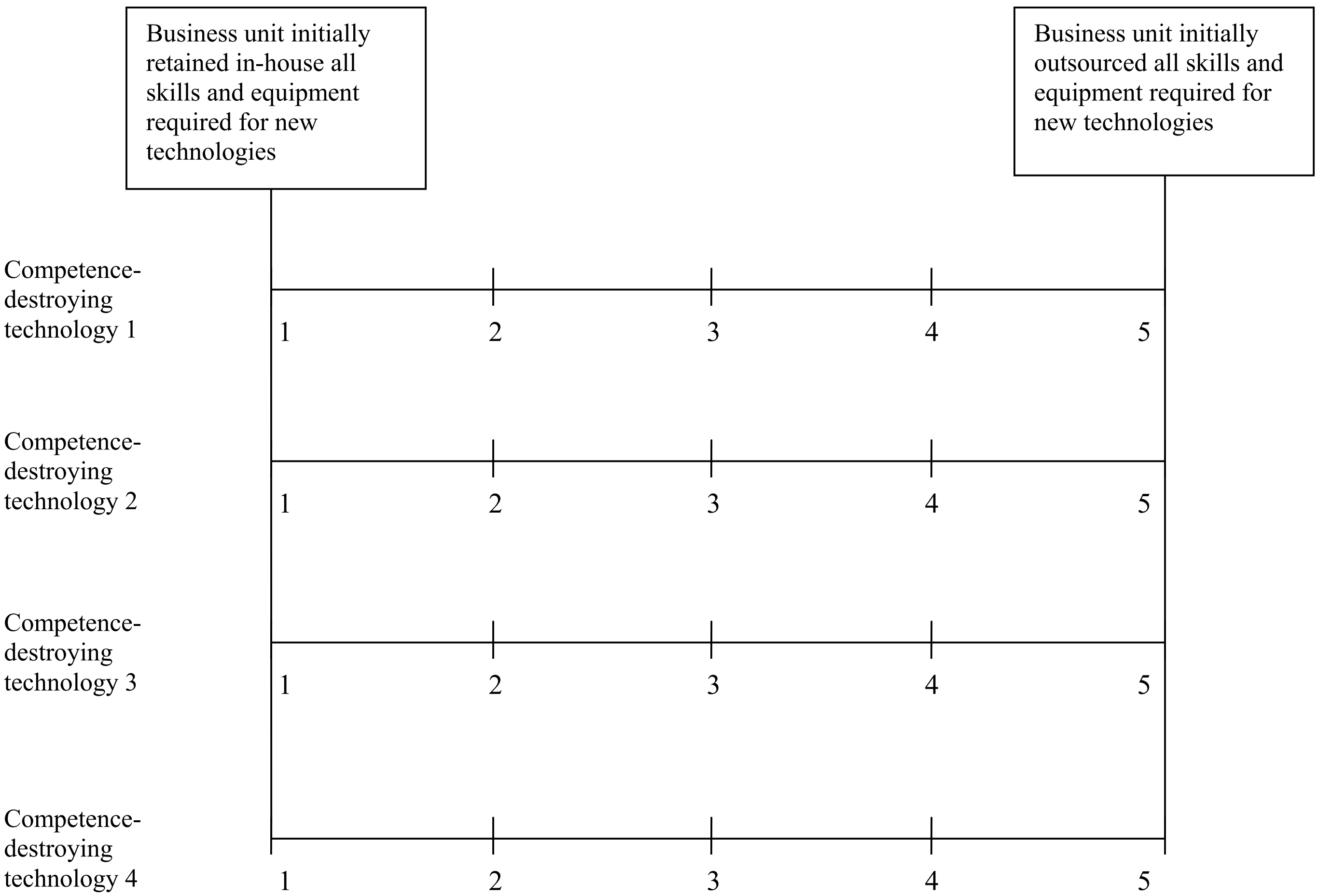
If your firm has never encountered any kind of competence-destroying technology (i.e. if you had to leave the table blank in question 1.5), please skip to ***Question 3.1***. Otherwise, please continue on to the next question in Section 2.

2.0 *Supplier Relationships in the Face of Competence-Destroying Technologies*

2.1 For each of the competence-destroying technological changes that you identified in question 1.5, did your business unit maintain relationships with the same suppliers after the competence-destroying technologies were introduced? Please circle the numbers on the scales below that best describe your answers.



2.2 When initially reacting to each of the competence-destroying technological changes identified in question 1.5, to what degree did your business unit outsource the skills and equipment that are related to the new technologies? Please circle the numbers on the scales below that best describe your answers.



2.3 When reacting to the introduction of each of the competence-destroying technologies identified in question 1.5, were your existing suppliers able to learn the new skills underpinning the new technologies? Please circle the numbers on the scales below that best describe your answers.

	Existing suppliers are unable to learn new skills underlying competence-destroying technologies				Existing suppliers able to quickly learn new skills underlying competence-destroying technologies
Competence-destroying technology 1	1	2	3	4	5
Competence-destroying technology 2	1	2	3	4	5
Competence-destroying technology 3	1	2	3	4	5
Competence-destroying technology 4	1	2	3	4	5

2.4 Considering only the ***first*** competence-destroying technology you identified in question 1.5, please answer yes or no to each of the following questions about the characteristics of the new technology.

	Yes	**No**
Was the new technology so different from previous technologies that the skills of employees were rendered obsolete?	❑	❑
Was the new technology so different from previous technologies that incumbent firms—that is, those that had a lot of experience with the previous technologies—were handicapped in their attempts to exploit the change?	❑	❑
When it was introduced, did the new technology render obsolete the organizational routines and procedures of incumbent firms?	❑	❑
Did the competence-destroying technology actually result in worse product performance when it was first introduced (but may have improved later to surpass performance of established technologies)?	❑	❑
Did products featuring the competence-destroying technology initially appeal to a few fringe (and generally new) customers before they were adopted in mainstream markets?	❑	❑
Were products featuring the competence-destroying technology *cheaper* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology *simpler* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology s*maller* than products based on more established technologies?	❑	❑

2.5 Considering only the ***second*** competence-destroying technology you identified in question 1.5, please answer yes or no to each of the following questions about the characteristics of the new technology.

	Yes	**No**
Was the new technology so different from previous technologies that the skills of employees were rendered obsolete?	❑	❑
Was the new technology so different from previous technologies that incumbent firms—that is, those that had a lot of experience with the previous technologies—were handicapped in their attempts to exploit the change?	❑	❑
When it was introduced, did the new technology render obsolete the organizational routines and procedures of incumbent firms?	❑	❑
Did the competence-destroying technology actually result in worse product performance when it was first introduced (but may have improved later to surpass performance of established technologies)?	❑	❑
Did products featuring the competence-destroying technology initially appeal to a few fringe (and generally new) customers before they were adopted in mainstream markets?	❑	❑
Were products featuring the competence-destroying technology *cheaper* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology *simpler* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology s*maller* than products based on more established technologies?	❑	❑

2.6 Considering only the ***third*** competence-destroying technology you identified in question 1.5, please answer yes or no to each of the following questions about the characteristics of the new technology.

	Yes	**No**
Was the new technology so different from previous technologies that the skills of employees were rendered obsolete?	❑	❑
Was the new technology so different from previous technologies that incumbent firms—that is, those that had a lot of experience with the previous technologies—were handicapped in their attempts to exploit the change?	❑	❑
When it was introduced, did the new technology render obsolete the organizational routines and procedures of incumbent firms?	❑	❑
Did the competence-destroying technology actually result in worse product performance when it was first introduced (but may have improved later to surpass performance of established technologies)?	❑	❑
Did products featuring the competence-destroying technology initially appeal to a few fringe (and generally new) customers before they were adopted in mainstream markets?	❑	❑
Were products featuring the competence-destroying technology *cheaper* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology *simpler* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology s*maller* than products based on more established technologies?	❑	❑

2.7 Considering only the ***fourth*** competence-destroying technology you identified in question 1.5, please answer yes or no to each of the following questions about the characteristics of the new technology.

	Yes	**No**
Was the new technology so different from previous technologies that the skills of employees were rendered obsolete?	❑	❑
Was the new technology so different from previous technologies that incumbent firms—that is, those that had a lot of experience with the previous technologies—were handicapped in their attempts to exploit the change?	❑	❑
When it was introduced, did the new technology render obsolete the organizational routines and procedures of incumbent firms?	❑	❑
Did the competence-destroying technology actually result in worse product performance when it was first introduced (but may have improved later to surpass performance of established technologies)?	❑	❑
Did products featuring the competence-destroying technology initially appeal to a few fringe (and generally new) customers before they were adopted in mainstream markets?	❑	❑
Were products featuring the competence-destroying technology *cheaper* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology *simpler* to use than products based on more established technologies?	❑	❑
Were products featuring the competence-destroying technology s*maller* than products based on more established technologies?	❑	❑

3.0 VALUE OF LONG-TERM SUPPLIER RELATIONSHIPS

3.1 Compared to competitors in your industry, how much value does your business unit place on long-term relationships with its suppliers? Please circle the number on the scale below that best describes your answer.

Business unit places less value on long-term supplier relationships than competitors do				Business unit places more value on long-term supplier relationships than competitors do
1	2	3	4	5

3.2 Does your business unit rely on suppliers to bear some of the costs associated with acquiring new technologies? Please circle the number on the scale below that best describes your answer.

Suppliers bear none of the costs associated with acquiring new technologies				Suppliers bear all costs associated with acquiring new technologies
1	2	3	4	5

3.3 On average, how important a role have your suppliers played in the development of new technologies in the past? Please circle the number on the scale below that best describes your answer.

Suppliers played no role whatsoever in the development of new technologies in the past				Suppliers played very important role in the development of new technologies in the past
1	2	3	4	5

3.4 How important a role do you think your suppliers will play in the development of new technologies in the future? Please circle the number on the scale below that best describes your answer.

Suppliers will play no role whatsoever in the development of new technologies in the future				Suppliers will play very important role in the development of new technologies in the future
1	2	3	4	5

3.5 As a technology matures, how does your business unit typically change its make-buy strategy for major components and processes associated with that technology? Please circle the number on the scale below that best describes your answer.

Business unit is more likely to bring technology in-house as it matures				Business unit is more likely to outsource technology as it matures
1	2	3	4	5

4.0 HOW SUCCESSFUL IS YOUR BUSINESS UNIT?

4.1 By your estimation, how does your business unit's current overall revenue market share compare to that of direct competitors within your industry? Please circle the number on the scale below that best describes your answer.

Your business unit's revenue market share lags far behind that of market leader				Your business unit's revenue market share is top among direct competitors
1	2	3	4	5

4.2 By your estimation, how does your business unit's average profitability over the last three years compare to that of direct competitors within your industry? Please circle the number on the scale below that best describes your answer.

Your business unit's three-year profitability lags far behind that of market leader				Your business unit's three-year profitability is top among direct competitors
1	2	3	4	5

4.3 By your estimation, how does your business unit's current overall sales growth compare to that of direct competitors within your industry? Please circle the number on the scale below that best describes your answer.

Your business unit's sales growth lags far behind that of market leader				Your business unit's sales growth is top among direct competitors
1	2	3	4	5

4.4 By your estimation, how does your business unit's current overall financial performance compare to that of direct competitors within your industry? Please circle the number on the scale below that best describes your answer.

Your business unit's overall financial performance lags far behind that of market leader				Your business unit's overall financial performance is top among direct competitors
1	2	3	4	5

We are only too happy to share the findings of this survey with you at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world. If you would like us to share the results with you, please write your e-mail address below. This address will not be used for any purpose other than providing you with the results, and will not be passed on to any other organization or person.

your e-mail: ______________________________

Thank you!

The survey is complete. Please return it in the enclosed FREEPOST envelope to:

Rob Perrons
Institute for Manufacturing
FREEPOST NATE599
Mill Lane
Cambridge
CB2 1BR

office phone: (01223)-338-192
fax: (01223)-338-076
e-mail: rkp22@cam.ac.uk

APPENDIX C: FIRST COVER LETTER TO COMPANIES FOR MAILED SURVEY OF UK-BASED FIRMS

Rob Perrons
Centre for Strategy and Performance

Mr. John Smith
Head Technology Manager
World's Best High Tech Company
1 Technology Road
Innovationville
Postal Code

UNIVERSITY OF CAMBRIDGE

Institute for Manufacturing

Tuesday, 4 March 2003

Mr Smith:

The breakneck pace of technological change in today's world represents a serious strategic problem for almost any manufacturing company. Innovation can be both the creator and destroyer of industries and corporations. A firm's approach to outsourcing is one particularly important element of its overall strategy for dealing with new technologies.

We are trying to understand how firms respond to significant technological change by surveying a cross section of decision-makers from companies around the world. This research is intended to identify technology management and procurement strategies that bring about improved business performance in the long-term.

I am writing to ask for your help in this. We have carefully selected a range of companies from different manufacturing sectors, and your response will therefore be very valuable towards ensuring a representative view. The survey consists of only 21 questions, and you may be assured of complete confidentiality. Your name will never be written on the survey. If you are not well placed in your organization to respond to this survey but know of someone in your business unit who may be, it would be much appreciated if you could provide their contact information so that we may request their participation.

We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world.

We very much hope that you will be able to participate. Please feel free to contact me at the address below if you have any questions. Thank you for your help.

Sincerely,

Rob Perrons
Industrial Research Fellow

APPENDIX D: FIRST COVER LETTER TO COMPANIES FOR INTERNET-BASED SURVEY OF INTERNATIONAL FIRMS

Rob Perrons
Centre for Strategy and Performance

Mr. John Smith
Head Technology Manager
World's Best High Tech Company
1 Technology Road
Innovationville
Postal Code
Country

UNIVERSITY OF CAMBRIDGE

Institute for Manufacturing

Tuesday, 4 March 2003

Mr Smith:

The breakneck pace of technological change in today's world represents a serious strategic problem for almost any manufacturing company. Innovation can be both the creator and destroyer of industries and corporations. A firm's approach to outsourcing is one particularly important element of its overall strategy for dealing with new technologies.

We are trying to understand how firms respond to significant technological change by surveying a cross section of decision-makers from companies around the world. This research is intended to identify technology management and procurement strategies that bring about improved business performance in the long-term.

I am writing to ask for your help in this. We have carefully selected a range of companies from different manufacturing sectors to participate in an on-line survey, and your response will therefore be very valuable towards ensuring a representative view. The survey consists of only 21 questions, and you may be assured of complete confidentiality. To complete the survey, please use the following information:

web address:	www.cambridge-survey.com
user name:	cambridge
password:	technology
serial number:	THEIR NUMBER HERE

We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world. We very much hope that you will be able to participate. Please feel free to contact me at the address below if you have any questions. Thank you for your help.

Sincerely,

Rob Perrons
Industrial Research Fellow

APPENDIX E: REMINDER POSTCARD TO COMPANIES FOR MAILED SURVEY OF UK-BASED FIRMS

[Note: what follows was written on the back of the postcard sent to each firm.]

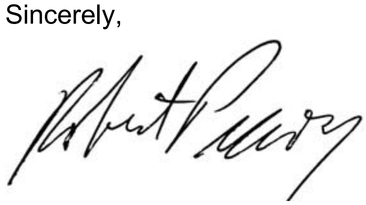
Tuesday, 11 March 2003

We mailed a survey to you last week as part of our investigation into companies' outsourcing policies in the face of significant technological change. If you have already completed and returned it to us, please accept our sincere thanks. If not, please do so today. A carefully selected range of firms was chosen from different manufacturing sectors for this survey, and your response will therefore be very valuable towards ensuring a representative view.

We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world. The survey consists of only 21 questions, and you may be assured of complete confidentiality.

If by some chance you did not receive the survey, or if it was misplaced, please contact me via e-mail at <rkp22@cam.ac.uk> and I will get another one in the mail to you today. Thank you for your help.

Sincerely,



Rob Perrons
Industrial Research Fellow

APPENDIX F: REMINDER POSTCARD TO COMPANIES FOR INTERNET-BASED SURVEY OF INTERNATIONAL FIRMS

[Note: what follows was written on the back of the postcard sent to each firm.]

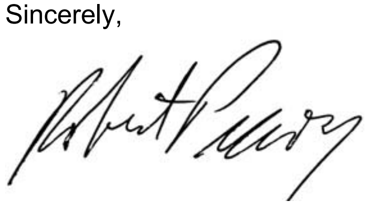
Tuesday, 11 March 2003

Last week, we mailed you a WWW address and password linking you to an on-line survey about outsourcing policies in the face of significant technological change. If you have already visited the web site and completed the survey, please accept our sincere thanks. If not, please do so today. A carefully selected range of companies was chosen from different manufacturing sectors for this survey, and your response will therefore be very valuable towards ensuring a representative view.

We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world. The survey consists of only 21 questions, and you may be assured of complete confidentiality.

If by some chance you did not receive the WWW address and your password for the survey, or if this information was misplaced, please contact me via e-mail at <rkp22@cam.ac.uk> and I will make sure that this information is promptly re-sent to you. Thank you for your help.

Sincerely,



Rob Perrons
Industrial Research Fellow

APPENDIX G: FINAL COVER LETTER TO COMPANIES FOR MAILED SURVEY OF UK-BASED FIRMS

Rob Perrons
Centre for Strategy and Performance

Mr. John Smith
Head Technology Manager
World's Best High Tech Company
1 Technology Road
Innovationville
Postal Code

UNIVERSITY OF CAMBRIDGE

Institute for Manufacturing

Tuesday, 25 March 2003

Mr Smith:

About three weeks ago I wrote to you seeking your opinions on technology management and outsourcing strategies. As of today we have not yet received your completed survey.

Our research team has undertaken this study to identify technology management and procurement strategies that bring about improved business performance in the long-term. I am writing to ask again for your help in this. We have carefully selected a range of companies from different manufacturing sectors to participate in the survey. Your opinions and perspectives are therefore critical to the success of this investigation. The survey consists of only 21 questions, and you may be assured of complete confidentiality. Your name will never be written on the survey. If you are not well placed in your organization to respond to this survey but know of someone in your business unit who may be, it would be much appreciated if you could pass it on to them.

We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world.

In the event that your copy of the survey has been misplaced, a replacement is enclosed.

Please feel free to contact me at the address below if you have any questions. Your cooperation is greatly appreciated.

Sincerely,

Rob Perrons
Industrial Research Fellow

APPENDIX H: FINAL COVER LETTER TO COMPANIES FOR INTERNET-BASED SURVEY OF INTERNATIONAL FIRMS

Rob Perrons
Centre for Strategy and Performance

Mr. John Smith
Head Technology Manager
World's Best High Tech Company
1 Technology Road
Innovationville
Postal Code
Country

UNIVERSITY OF CAMBRIDGE

Institute for Manufacturing

Tuesday, 25 March 2003

Mr Smith:

About three weeks ago I wrote to you seeking your opinions on technology management and outsourcing strategies. As of today you have not yet completed our on-line survey.

Our research team has undertaken this study to identify technology management and procurement strategies that bring about improved business performance in the long-term. I am writing to ask again for your help in this. We have carefully selected a range of companies from different manufacturing sectors to participate in the on-line survey, and your response will therefore be very valuable towards ensuring a representative view. It is essential that each person in the sample participate. The survey consists of only 21 questions, and you may be assured of complete confidentiality. To complete the survey, please use the following information:

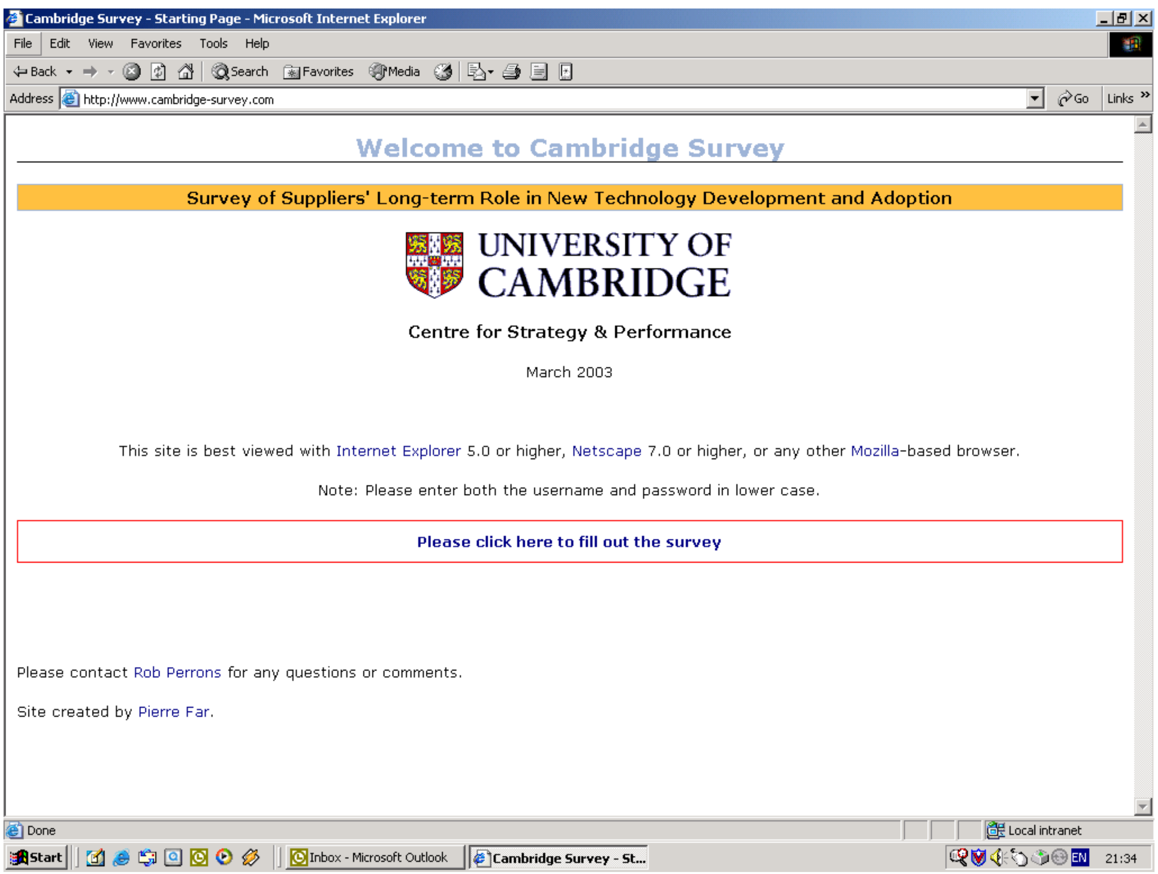
web address:	www.cambridge-survey.com
user name:	cambridge
password:	technology
serial number:	THEIR NUMBER HERE

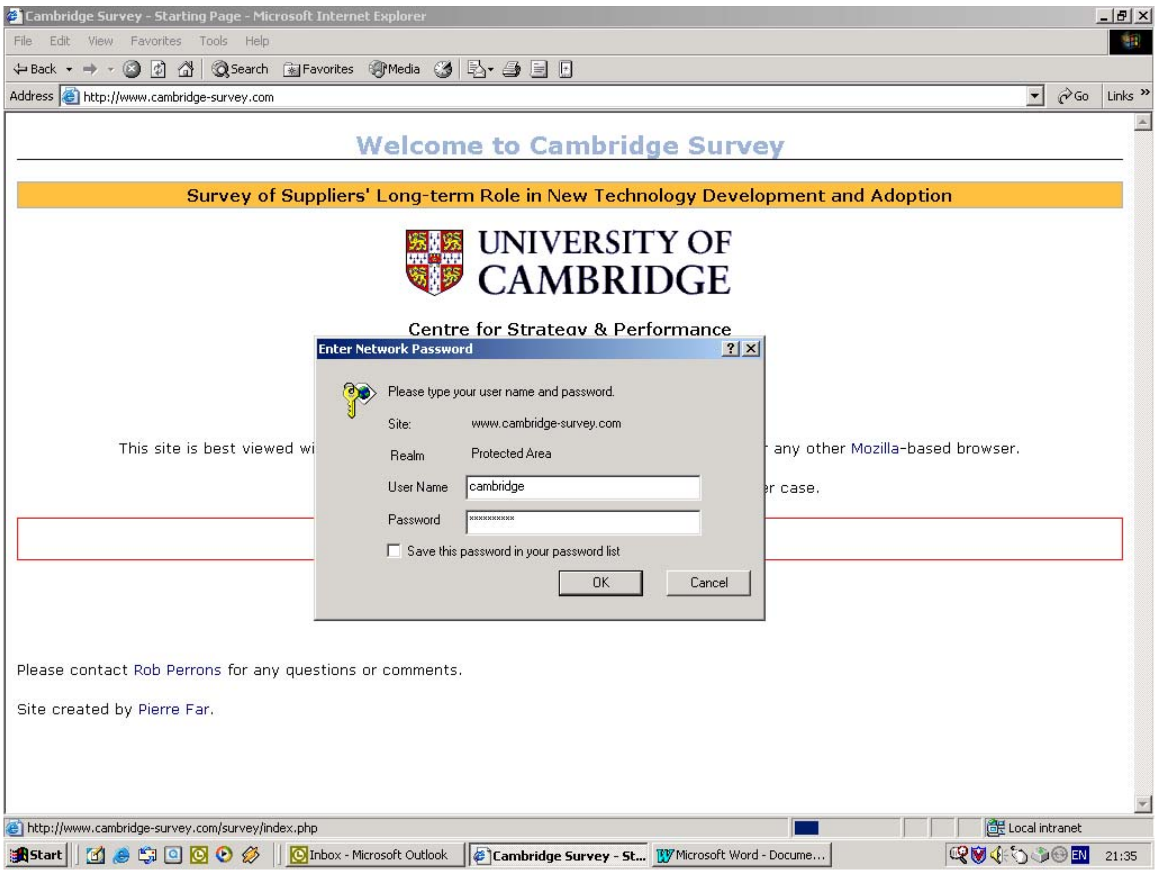
We will share the findings of this survey with all participants at no cost. Several world-class companies have already signed on to this research project, and your participation in this investigation would therefore represent an opportunity for cross-learning with leading firms around the world. We very much hope that you will be able to participate. Please feel free to contact me at the address below if you have any questions. Your cooperation is greatly appreciated.

Sincerely,

Rob Perrons
Industrial Research Fellow

APPENDIX I: SELECTED SCREEN SHOTS FROM ONLINE VERSION OF SURVEY FOR INTERNATIONAL RESPONDENTS

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Welcome to Cambridge Survey
Survey of Suppliers' Long-term Role in New Technology Development and Adoption
UNIVERSITY OF CAMBRIDGE
Centre for Strategy & Performance
Enter Network Password
Please type your user name and password.
Site: www.cambridge-survey.com
Realm Protected Area
User Name cambridge
Password
Save this password in your password list
OK
Cancel
This site is best viewed wi
any other Mozilla-based browser.
r case.
Please contact Rob Perrons for any questions or comments.
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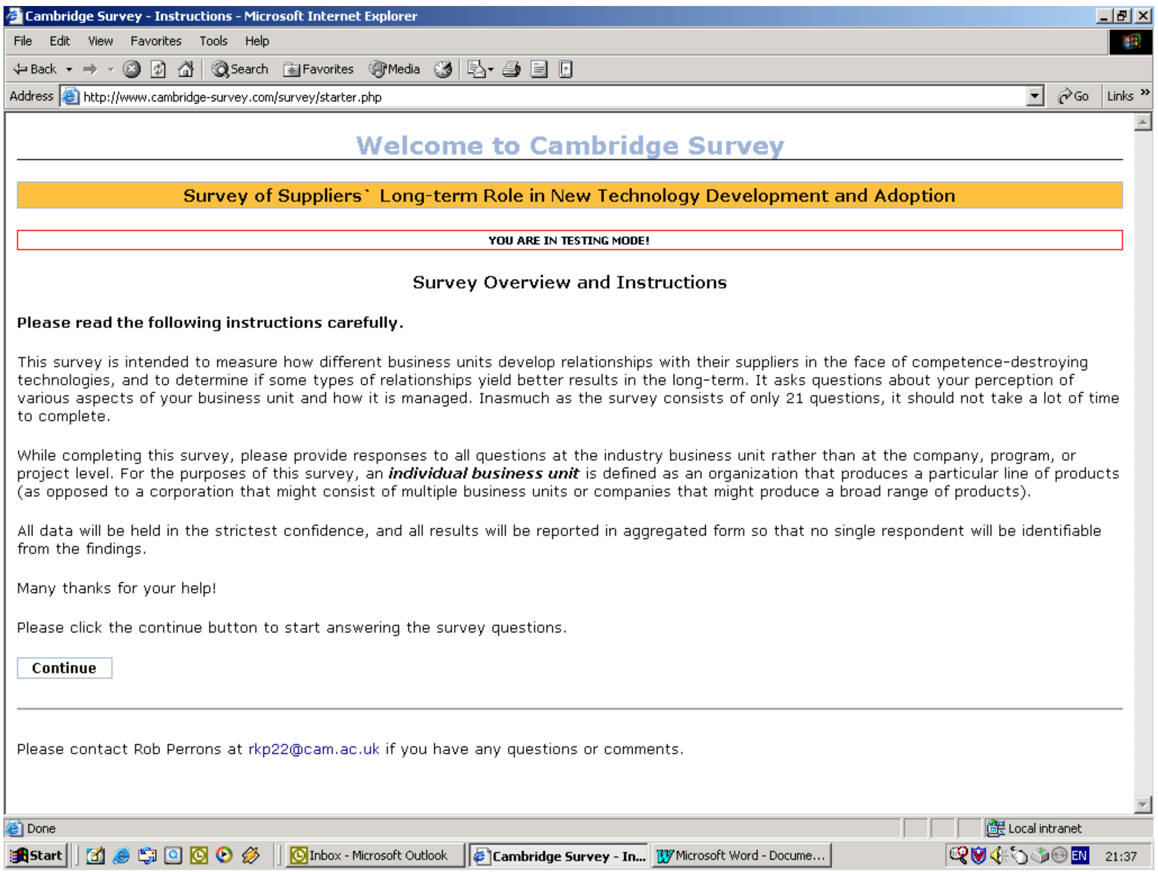
Cambridge Survey - Instructions - Microsoft Internet Explorer
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Welcome to Cambridge Survey
Survey of Suppliers` Long-term Role in New Technology Development and Adoption
YOU ARE IN TESTING MODE!
Survey Overview and Instructions
Please read the following instructions carefully.
This survey is intended to measure how different business units develop relationships with their suppliers in the face of competence-destroying technologies, and to determine if some types of relationships yield better results in the long-term. It asks questions about your perception of various aspects of your business unit and how it is managed. Inasmuch as the survey consists of only 21 questions, it should not take a lot of time to complete.
While completing this survey, please provide responses to all questions at the industry business unit rather than at the company, program, or project level. For the purposes of this survey, an individual business unit is defined as an organization that produces a particular line of products (as opposed to a corporation that might consist of multiple business units or companies that might produce a broad range of products).
All data will be held in the strictest confidence, and all results will be reported in aggregated form so that no single respondent will be identifiable from the findings.
Many thanks for your help!
Please click the continue button to start answering the survey questions.
Continue
Please contact Rob Perrons at rkp22@cam.ac.uk if you have any questions or comments.
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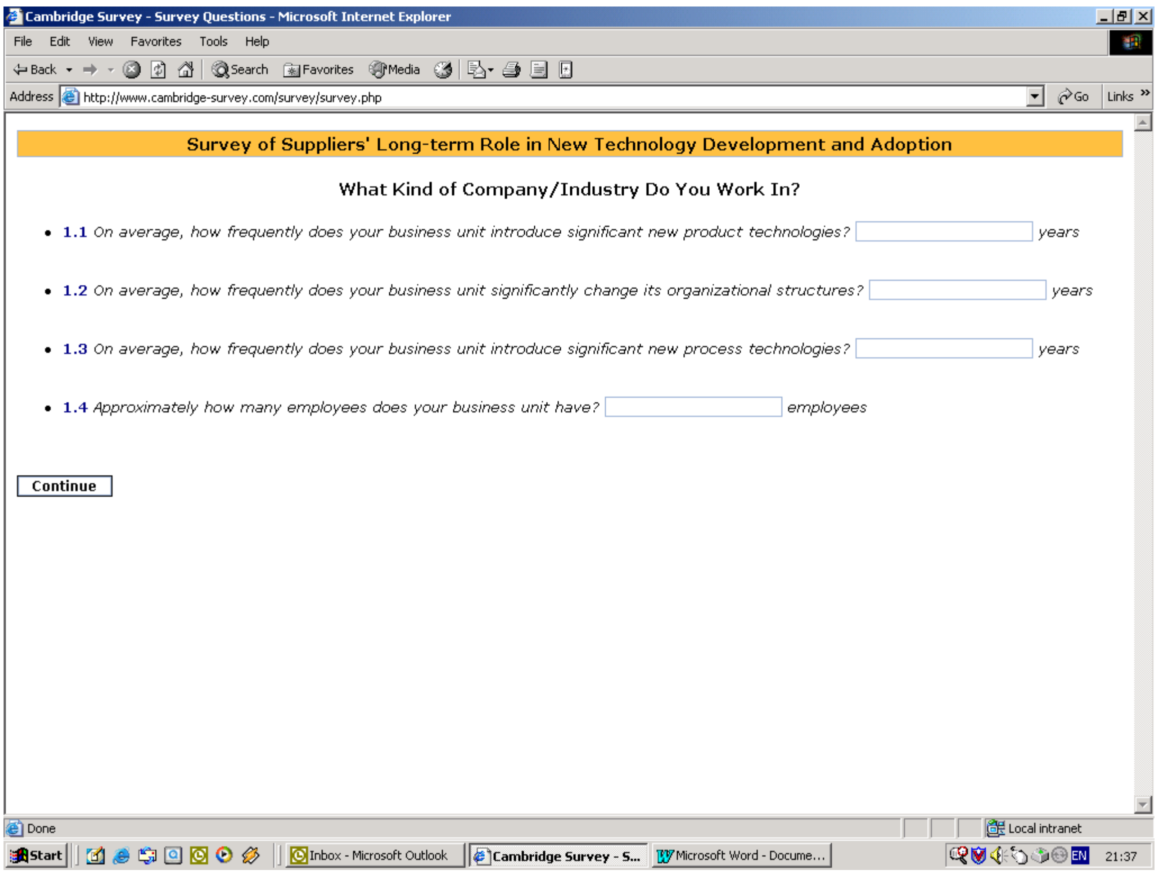
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Survey of Suppliers' Long-term Role in New Technology Development and Adoption
What Kind of Company/Industry Do You Work In?
1.1 On average, how frequently does your business unit introduce significant new product technologies? years
1.2 On average, how frequently does your business unit significantly change its organizational structures? years
1.3 On average, how frequently does your business unit introduce significant new process technologies? years
1.4 Approximately how many employees does your business unit have? employees
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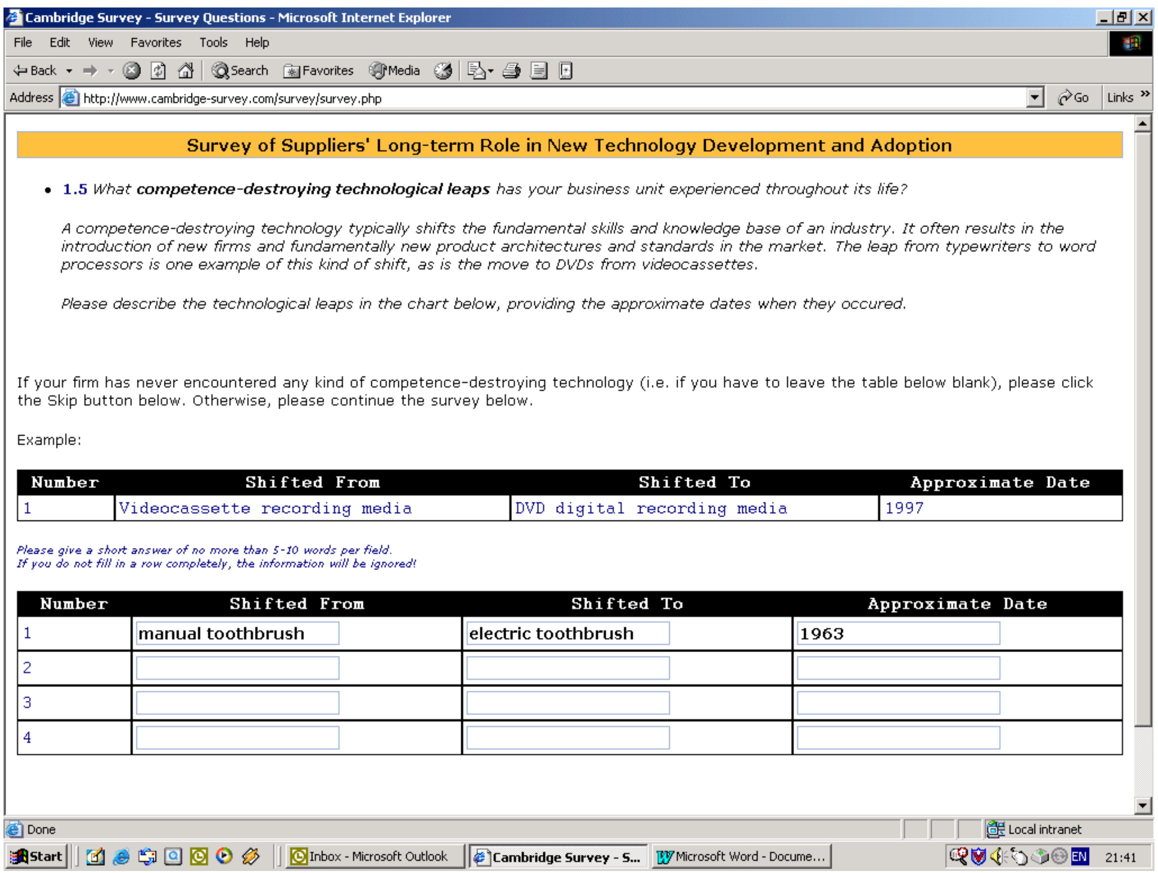

Cambridge Survey - Survey Questions - Microsoft Internet Explorer

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Address http://www.cambridge-survey.com/survey/survey.php

Survey of Suppliers' Long-term Role in New Technology Development and Adoption

- **1.5** *What* ***competence-destroying technological leaps*** *has your business unit experienced throughout its life?*

  A competence-destroying technology typically shifts the fundamental skills and knowledge base of an industry. It often results in the introduction of new firms and fundamentally new product architectures and standards in the market. The leap from typewriters to word processors is one example of this kind of shift, as is the move to DVDs from videocassettes.

  Please describe the technological leaps in the chart below, providing the approximate dates when they occured.

If your firm has never encountered any kind of competence-destroying technology (i.e. if you have to leave the table below blank), please click the Skip button below. Otherwise, please continue the survey below.

Example:

Number	Shifted From	Shifted To	Approximate Date
1	Videocassette recording media	DVD digital recording media	1997

Please give a short answer of no more than 5-10 words per field.
If you do not fill in a row completely, the information will be ignored!

Number	Shifted From	Shifted To	Approximate Date
1	manual toothbrush	electric toothbrush	1963
2			
3			
4			

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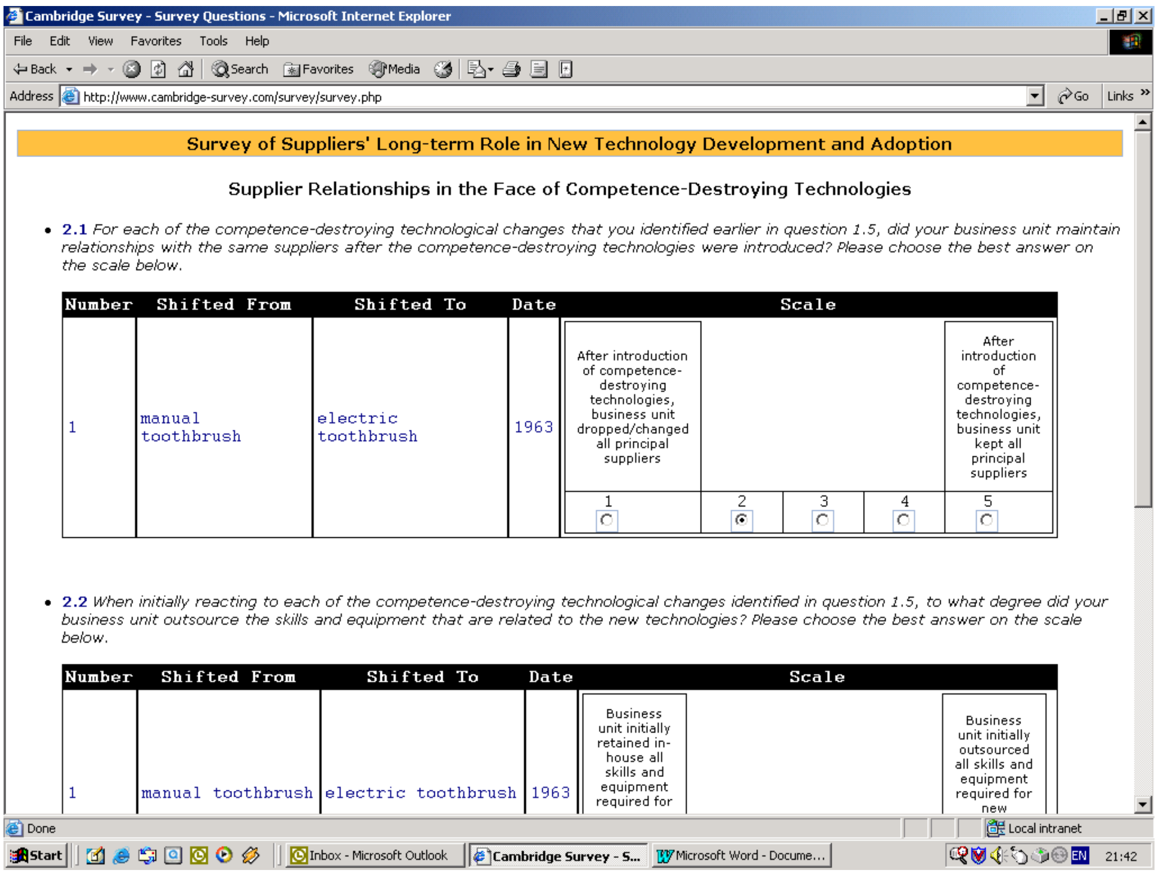
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Back Search Favorites Media
Address http://www.cambridge-survey.com/survey/survey.php
Go Links
Survey of Suppliers' Long-term Role in New Technology Development and Adoption
Supplier Relationships in the Face of Competence-Destroying Technologies
2.1 For each of the competence-destroying technological changes that you identified earlier in question 1.5, did your business unit maintain relationships with the same suppliers after the competence-destroying technologies were introduced? Please choose the best answer on the scale below.
Number Shifted From Shifted To Date Scale
1 manual toothbrush electric toothbrush 1963
After introduction of competence-destroying technologies, business unit dropped/changed all principal suppliers
After introduction of competence-destroying technologies, business unit kept all principal suppliers
1 2 3 4 5
2.2 When initially reacting to each of the competence-destroying technological changes identified in question 1.5, to what degree did your business unit outsource the skills and equipment that are related to the new technologies? Please choose the best answer on the scale below.
Number Shifted From Shifted To Date Scale
1 manual toothbrush electric toothbrush 1963
Business unit initially retained in-house all skills and equipment required for
Business unit initially outsourced all skills and equipment required for new
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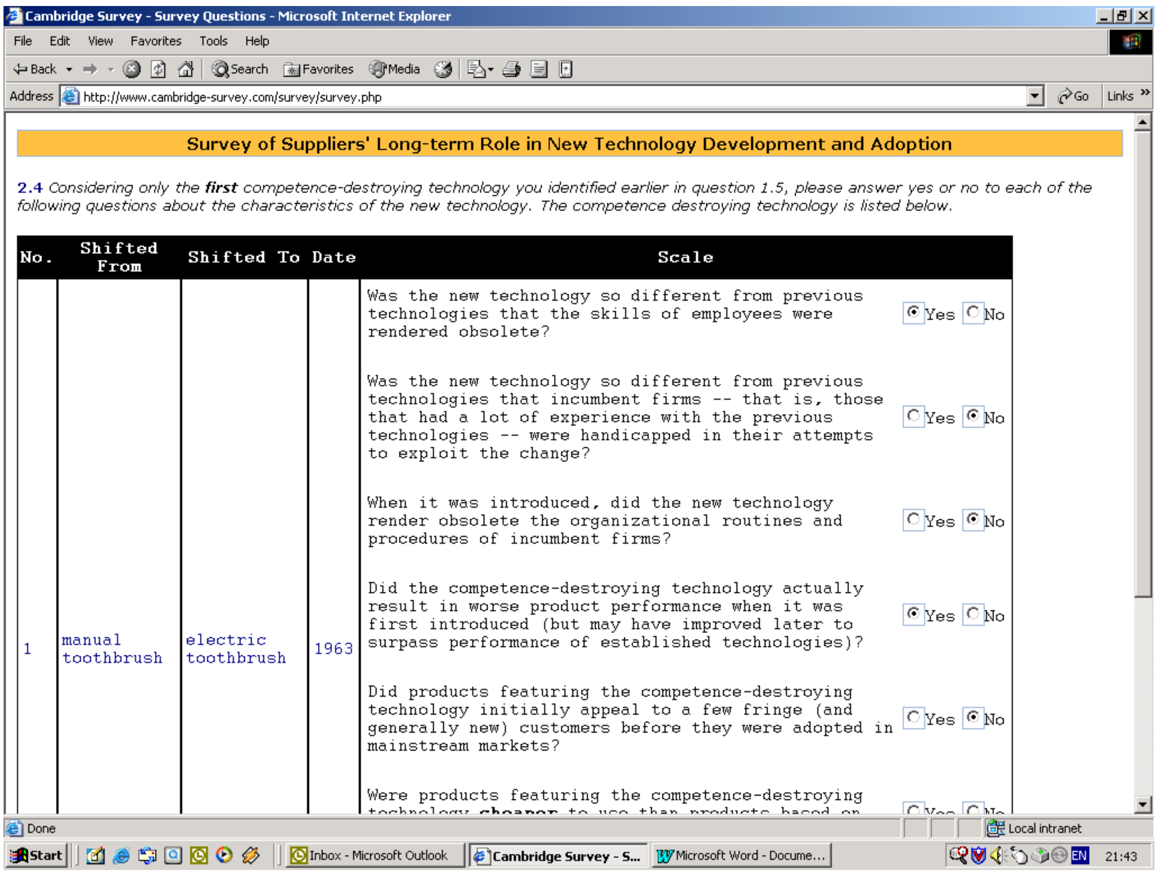
Cambridge Survey - Survey Questions - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Address http://www.cambridge-survey.com/survey/survey.php
Go Links
Survey of Suppliers' Long-term Role in New Technology Development and Adoption
2.4 Considering only the **first** competence-destroying technology you identified earlier in question 1.5, please answer yes or no to each of the following questions about the characteristics of the new technology. The competence destroying technology is listed below.
No. Shifted From Shifted To Date Scale
1 manual toothbrush electric toothbrush 1963
Was the new technology so different from previous technologies that the skills of employees were rendered obsolete? Yes No
Was the new technology so different from previous technologies that incumbent firms -- that is, those that had a lot of experience with the previous technologies -- were handicapped in their attempts to exploit the change? Yes No
When it was introduced, did the new technology render obsolete the organizational routines and procedures of incumbent firms? Yes No
Did the competence-destroying technology actually result in worse product performance when it was first introduced (but may have improved later to surpass performance of established technologies)? Yes No
Did products featuring the competence-destroying technology initially appeal to a few fringe (and generally new) customers before they were adopted in mainstream markets? Yes No
Were products featuring the competence-destroying
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APPENDIX J: COMPARISON OF PARAMETRIC AND NON-PARAMETRIC RESULTS

	Average % difference in Correlation	Average % difference in Significance
UK data		
Fast clockspeed	68	63
Medium clockspeed	40	27
Slow clockspeed	52	38
International data		
Fast clockspeed	26	53
Medium clockspeed	167	25

Table J.1: Average Differences Between Spearman and Pearson Measures