Strategies for Successful Technology Integration

by

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Submitted to the Alfred P. Sloan School of Management
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ABSTRACT

The business environment in many industries is increasingly relying on an ever-widening set of disparate technologies that must be linked together to form products, and thus, the importance of technology integration is growing. Technology integration was defined and studied from a strategic and operational perspective to identify key factors which promote superior performance. From a strategic perspective, it is shown through an evaluation of the research into product development and through a case study of residential central air conditioners, that technology integration must be coherent and synergistic with the business strategy of a firm. The set of viable technological opportunities can both drive business strategy and be driven by business strategy. The greatest success is achieved when both occur simultaneously in a synergistic manner. From an operational perspective, technology integration was studied to identify factors which enable the effective combination of technologies and components together to form the product system. A combination of a review of the research into product development, and interviews with experts in systems integration, points to several broad categories of factors which promote superior technology integration. Decisions and organizational structures that 1) promote business and technical linkages, 2) prevent biases, and 3) promote product design iteration are suggested as factors which are under the control of management and which significantly contribute to greater technology integration performance. Factors which increase the difficulty of technology integration that are typically beyond the control of management are technology and market uncertainty, the complexity of interaction between the components in the product system, and the degree of disruption.

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None of my significant achievements have been accomplished alone, and this thesis and program of study are no exception.

Every journey has a beginning, and the success of this effort started with the energy and desire to learn that my parents instilled within me - I am ever grateful to my parents, Bill and Jean. I cannot say enough about the support from my partner in life, Laura, and from my son, David, who both bore the brunt of this program through my absence. Thanks to you two for supporting me and keeping me centered and motivated.

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Chapter 1 - Introduction

There has been more information produced in the last 30 years than during the previous 5,000. The information supply available to us doubles every 5 years.
-Richard Saul Wurman (Wurman 1989)

Technology progress……….has slowed markedly.
-The End of The Future (Gimpel 1995)

The Age of Convergence

The question of how the pace of technological change today compares with past history is the source of much debate today. Many believe that the changes that we must contend with are unprecedented in magnitude at least since the industrial revolution. Others counter that the changes in today's technological landscape are of the same or diminished magnitude on a relative basis to those that have occurred for centuries. Despite widely varying positions on the answer to this question, many agree that the number and breadth of technologies that businesses today must consider as being relevant is much broader than at any time in the past.

One major driver behind this dramatic increase in the technological breadth necessary to be competitive is convergence. On an industry level, convergence represents the uniting of once very disparate industries together to form a new industry with new products and/or services. On a product level, convergence is the combination of functions, previously available only on separate products, which are now embodied in a single product.

The unification of once separate industries and its products is possibly best illustrated today by the convergence of computers, telecommunications, and entertainment (Yoffie 1996). Companies such as AT&T, TCI, Time-Warner, Cablevision, and others are racing to pursue strategies of delivering products that bring together voice, data, television, and entertainment/information content. Personal video conferencing, video-on-demand, interactive television, multi-media learning, real-time corporate information networks, are just a few of the products and services envisioned from this union of established technologies.

Convergence on the product level is also pervasive from the brand new internet industry to the hundred year-old automobile industry. Thirty years ago paper copiers were dominated by Xerox, computers and peripherals by IBM. Today, Canon offers the CFX L4500 which is a single unit that functions as a copier, a computer printer, a fax machine, a scanner, and includes telephony functions.[1] Until recently, consumers needed a second vehicle, different from their sedan, to haul cargo and to use in off-road situations. The sport utility vehicle created by the United States automobile manufacturers integrated the ruggedness and off-road capabilities of trucks with the ride and handling characteristics of the traditional sedan. Consumers no longer need to trade-off these functions or to purchase two vehicles to obtain the functionality that the sport utility vehicle offers.

Although convergence provides users with superior performance and functionality often at lower cost, it presents a particularly daunting challenge to business leaders who are faced with integrating the disparate technologies. New competencies may be required, while existing competencies may be viewed as unnecessary and even a hindrance. In-house development versus outsourcing some or all of the component technologies embodied in its product must be considered. These are but a few of the factors that managers must consider in crafting a successful strategy. These challenges become real when one looks at the Canon CFX L4500 mentioned above. How did Canon first determine that these five functions/technologies needed to be integrated into a single product? Second, once decided, how did Canon gain the expertise in the areas such as telephony which is outside their previous experience base?

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[1]Canon debuts five - function laser printer, PC Week. **14:** 104, 1997.

Thus, the acceleration of convergence is placing greater emphasis on being able to integrate technology as critical competitive competency. The success of major resource commitments is riding on the ability to make the integration happen. AT&T will spend between $8 billion and $9 billion in the near term to bring new technologies together such as voice, data, wireless, and internet for corporate customers (Lapolla 1997). Yet, despite these high stakes, technology integration is not new. At some level, almost all products and services can be viewed as a combination of components that represent different technologies. Our transportation vehicles, home appliances, and manufacturing systems are all forms of significant mechanical and electronic integration. How have companies producing these products succeeded at technology integration? What strategies and organizational approaches have they found that promote technology integration? Answering these questions about existing products and firms may serve as guidance for those managers seeking to cope with new convergence of technologies. Providing this insight into the management-controllable factors which affect a firm's technology integration capability is the value proposition that I seek to address through this thesis.

Thesis Content and Scope

Despite argument of its significant and growing importance, there are no textbooks and few research papers which analyze and illuminate the success factors for technology integration. Even as a distinct element within studies of general technological innovation, scholars and business practitioners have paid little attention to the specific act of integrating technological components. Those that refer to integration, do so primarily from the context of bringing together different capabilities to form cross-function groups (e.g. Clark and Wheelwright 1993). But the process of bringing together disparate technologies to form a product or service is about much more than just cross-functional integrated product development (IPD) teams. It must include how the firm's business strategy is accounted for in the product design and execution, and it must consider how to ensure that the IPD teams have access to broad sources of technical and business information from which they can base their decisions upon. The lack of focus and research on technology integration is clearly a gap that deserves attention, particularly in light of the business imperatives discussed above. This thesis represents one small attempt to begin filling this gap with a clearer understanding of technology integration as a specific competency that can be managed and promoted.

The premise for this thesis comes from a deceptively simple question that Clay Christensen at Harvard Business School posed to me one day: If you give two firms the same box of components required to build a product, why does one firm produce a better performing product than the other? This question is simple because the answer is that one firm is "better" than the other. It is also deceptive in that it is not very clear what "better" is and how to achieve it from the perspective of a manager charged with running all or part of a firm.

Clay's question became even more puzzling when he pointed out that those firms which produced a comparatively poorer product, often had superior knowledge of the technologies and components that comprised the product. In his study of the computer disk drive industry, he found that IBM and HP increased the performance of their products at nearly the same rate, but by following very different strategies (Christensen 1992). IBM derived its performance improvement by periodically incorporating new component technologies that it had developed internally. HP, in contrast, improved the performance of its hard disk drives through continuous incremental innovations based on a stable set of technologies that it did not develop internally. HP was able to derive performance improvements from increasingly better integration compared to IBM which resorted to adoption of new technologies to keep the same pace of improvement. HP's superior ability at technology integration compared to IBM is somewhat puzzling since IBM clearly had much deeper knowledge of the individual component technologies for disk drives. In fact, IBM pioneered almost all of the innovations in the hard disk industry. Common sense would suggest that the greater knowledge about the component technologies possessed by IBM would enable them to wring greater performance out of a given set of components than HP. The answer to this paradox must lie within the process of technology integration and how a firm's strategy, structure and operational characteristics influence this capability.

These observations can be unsettling for leaders faced with integrating new technologies into their products as they deal with the acceleration of technological convergence. The answers to fundamental questions become less clear. For example, is it better for a firm to develop significant competencies in the development of the component technologies (as IBM did), or is the firm likely to be more successful if it outsources the components that make up its products? If one path is better than the other, how does the leader of the firm identify the appropriate strategy? As I will discuss later, the academic research and the popular business literature provide little specific guidance for the pursuit of superior technology integration.

This thesis seeks to begin to understand technology integration as a specific competency, and to present this understanding from the perspective of a manager of a firm so that it has a degree of usability and applicability. This perspective suggests that the framework of this understanding must be both fairly uncomplicated and incorporate factors that are under the direct or indirect control of a manager. I hope that the reader will agree that the proposed three dimensional framework of linkages, biases, and iteration is a useful way to not only think about technology integration, but to also motivate managerial decisions of organizational structure and firm strategy that will lead to superior capability in this area. Robust verification of this framework is beyond the scope of this thesis, yet, the empirical data presented in this study strongly suggests that it is clearly on the right track.

Thesis Structure

The understanding of technology integration begins in Chapter 2 with the development of a working definition and consideration of how technology integration performance can be measured. Chapter 3 explores the state-of-the-art in the understanding of innovation as it relates to the specific competency of technology integration. The most direct work on technology integration by Iansiti and Christensen is also explored. In Chapter 4, the fundamental competencies and factors that support superior technology integration are introduced. We will see that technology integration must be considered from both an operational and a strategic perspective. A framework is proposed which identifies three behaviors that managers must promote in order to achieve superior technology integration. Three environmental variables, outside of the control of a manager, are also identified which have equally significant impact on the success of technology integration. In Chapter 5, we see how technology integration and business strategies are strongly linked through a study of two firms in the residential central air conditioning industry. Chapter 6 concludes this thesis with a summary of key lessons learned from this investigation into technology integration and identifies further work that is needed to more fully understand this complex competency.

Chapter 2 - What is Technology Integration?

I suggested in the preceding chapter that the capability to integrate disparate technologies is becoming an increasingly important competence, and it is thus important to understand the factors that lead to success and failure in this endeavor. To accomplish this, we must first discuss what technology integration is and what parts of the product development process are included. Once we have a common frame of reference to discuss the subject, we then need a robust means to measure technology integration so that we can begin to make value judgments as to what leads to better or worse technology integration.

Definition of Technology Integration

Defining technology integration presents a particular challenge since limited studies have been conducted on this subject. It is only through repeated attempts to analyze and explain something that we can develop a highly meaningful and useable definition for it. Given that there is no consensus definition for technology integration, I shall propose a working definition that captures the essential competencies and builds on the thoughts of scholars which have recently explored this subject.

Marco Iansiti is one scholar who has specifically targeted his efforts to better understand technology integration. Although I will discuss his findings later in more detail, I believe it is worthwhile to use his definition for technology integration as a starting point. Within Iansiti's body of work there are subtlety different definitions proposed for technology integration. In one example, he focuses on the process of selecting among technical approaches and possibilities: *"Technology integration is the set of investigation and evaluation activities aimed at selecting the set of novel technical approaches to be followed in a development program" (Iansiti 1995)*. He further emphasizes this idea by stating that technology integration activities define the interaction between research and product development and that they are distinctly different from activities related to technology transfer.

Iansiti along with Clark present a slightly different definition of technology integration which is based on linking technological possibilities to the capability of the firm: *"Technology integration is the capacity to link the evolving base of technical knowledge (both inside and outside the firm) to the existing capability within the organization" (Iansiti and Clark 1994).* This definition emphasizes that an element of technology integration is the capability of the firm to exploit the technological possibilities that are available to it.

Iansiti's definitions lack some specific competencies which I believe are equally important to the process of technology integration. Specifically, he excludes what is conventionally referred to as the product development process from technology integration. I argue that the process of knitting together the selected technologies to form a product is also essential to the notion of technology integration. Mere selection of technical approaches to be used does not guarantee that they will be effectively integrated together. Furthermore, technology integration must not only select and combine technical possibilities into a product or service, but these steps must result in a product that is successful in the marketplace. The business landscape is littered with examples of products which technically outperformed the competition, yet were dismal failures in the marketplace. For example, Sony's Betamax architecture was technically superior to the VHS format, yet the Betamax succumbed to the market domination of VHS (Cusumano, Mylonadis et al. 1992).

Building on Iansiti's definitions, I propose that a comprehensive definition of technology integration must include three important competencies:

Selection: The selection among all possible technical approaches (both internal and external to the firm) to solve the product "problem"

Combination: The combination and integration of these selected approaches together to create the product or service

Market Success: The technical approaches are selected and combined in such a manner to produce a product that is highly valued by the market that is targeted for.

These competencies lead to the following definition for technology integration that serves as the basis for this study:

> *Technology integration is the process of selection and combination of technological possibilities into a product or service that is successful in the marketplace.*

This definition is very broad and it encompasses activities that range from being strategic to those that are very tactical. As we will see later, the "selection" element of the definition is often very strategic to the success of a firm. The eminence of many firms and products is based on the ability to select the "right' set of technologies that are bundled to meet customer needs. Technology integration also spans the more operational/tactical end of the spectrum where the process of combining the selected technologies to form the product occurs.

The definition of technology integration presented above begins to illuminate why this competency is both difficult to manage and why little attention has been paid to it in the academic literature. Simply stated, technology integration is a process that is very hard to grasp because it spans a large part of a firms business and technical activities that are generally under the responsibility of different functional organizations. There is unlikely to be a director of technology integration within a firm, yet there will be the leaders of business development, engineering, R&D, marketing, and manufacturing - all owning pieces of the technology integration process. In some sense, technology integration is a lens through which the linkages between various activities in the product development process can be viewed.

Measuring Technical Integration

How do we differentiate between "good" technology integration and "poor" technology integration? In other words, how do we measure the performance of a firm with respect to its ability to select and combine technological possibilities into a successful product? Measuring technology integration is vital to both understanding what it is as well as enabling management to make decisions that improve the outcome of the technology integration process. Appropriate performance metrics, however, are usually troublesome for firms to develop since it is difficult to capture the complexities of business performance with just a few quantifiable measurements. Technology integration is no different since it spans such a large range of the strategic continuum. Given this breadth, I suggest that technology integration must be measured from both the strategic and the operational/tactical perspectives if we are to gain a robust indication of performance. This is itself not an easy proposition since it is very difficult to measure the performance of "strategy" beyond looking at the financial performance which results from the combination of the firm's strategic and tactical activities.

Technical and Operational Perspective

Measures of technical performance and operational effectiveness have been the focus of the few published efforts to gauge technology integration. While I do not believe that they adequately address the strategic aspects of technology integration, they do serve as a starting point for comparing the technology integration competencies between firms.

Measures of product performance or other parameters that are attributable to the interconnection and integration of component technologies have been suggested as suitable metrics for technology integration. Iansiti, in his study of the mainframe computer industry, utilized the number of gates per square centimeter of silicon as a measure of the effectiveness of the integration achieved in producing a module for a mainframe computer (Iansiti 1995). This metric is a good indicator of technology integration performance since it depends on the electrical, thermal, and mechanical characteristics of the design. Christensen similarly utilized areal recording density as a measure of a manufacturer's ability to integrate the platter, head, motor, and other components together to produce a hard disk drive (Christensen 1992). I categorize these product performance and product attribute metrics as measures of the *technical effectiveness* of the technology integration process.

Technical effectiveness is not always sufficient to judge the success of technology integration. The elegant combination of different technologies to produce a product which fails to survive against the competition cannot be judged as successful technology integration. The battle between Sony and JVC for the video recorder market in the 1970's is an illustrative example. Sony was first to market with its Betamax which produced a superior picture quality compared to the VHS format introduced a year later by JVC. Despite Sony's first mover advantage, through which it captured 58% of the market in 1975-1977, Sony had all but stopped Beta VCR production by the late 1980's even though its product was technically superior. The success of the JVC VHS format over the Sony Beta format has been explained by Cusumano et al as attributable to a superior business strategy pursued by JVC and its parent Matsushita (Cusumano, Mylonadis et al. 1992). JVC's strategy was to build market acceptance for its VHS standard by aggressively pursuing both licensing and OEM agreements with other Japanese, US, and European firms. In contrast, Sony was initially reluctant to partner with other companies because it did not want to compromise the technical design of the Betamax to create an industry standard. JVC's strategy to partner with other companies and to compromise on their original design caused the VHS format to gain momentum that overwhelmed the Beta format in just a few years.

This case shows that it is the users of the product, which vote with their purchase decisions, who are the ultimate judge of whether a firm is successful in its endeavor to integrate technologies into a product. Thus, appropriate measures of technology integration must also directly or indirectly capture the *business effectiveness* of the product. Metrics different from those that capture the technical effectiveness of the technology integration may be required. For example, in the early days of the hard disk drive industry, recording density captured both the technical and business effectiveness of a firm's integration strategy since the overriding industry objective (and purchase decision) was to provide the greatest storage capacity in a form factor that could fit into the computer. Today, recording density remains a measure of technology integration capability since the capacity desired for personal computer hard drives continues to rapidly rise. However, areal recording density no longer totally captures the business effectiveness of technology integration in this industry since there are markets for hard disk drives which value other attributes, such as cost or reliability, more than recording density. Care must be exercised in selecting technical measures of performance to ensure that there are also primary factors which influence the purchase decision.

Second, we must consider how much effort and resources were devoted to the integration process. A well integrated product from an effectiveness perspective will ultimately not be successful if extraordinary resources, including time, capital, and labor, are required to achieve the integration. I term this dimension as the *efficiency* of the technology integration.

Strategic Perspective

As noted earlier, measuring technology integration performance from a strategic perspective is quite difficult since it requires the ability to link specific strategy decisions to measurable outcomes of firm performance. Yet firm performance is affected by all decisions, both tactical and strategic, as well as market and economic factors beyond the control of the firm. An assessment of what constitutes business strategy and how to ascertain its effectiveness is beyond the scope of this thesis and the reader is directed to the work of several scholars on this subject. Michael Porter continues to mature his thinking on what comprises strategy and how one can judge its overall effectiveness (Porter 1996). Hamel's recent thoughts suggest that business strategy must be assessed by how revolutionary its impact is on the industry (Hamel 1996). Hax offers a more pragmatic and traditional treatment on the process and frameworks for creating and assessing business strategies (Hax and Majluf 1996).

For the process of measuring technology integration from a strategic perspective, I will suggest later that we must judge the degree of coherency, alignment, and interdependence between the strategy for technology integration and the overall business strategy of the firm. A business strategy and a technology integration strategy that synergistically work together reinforce each other and offer the best opportunity for the firm to succeed. Traditional measures of firm success, such as revenues, returns on selected assets, or market share can also be used as additional indicators of technology integration performance from a strategic perspective.

Chapter 3 - The Foundations of Technology Integration

My discussions with both business leaders and academic scholars of innovation confirmed that understanding how to do technology integration well is of both great interest and concern. I found it surprising, however, that little research has been focused on technology integration as a fundamental competency. Why is this so if it is such an important concept? Part of the answer, I believe, is that technology integration gets lost in the pursuit of the overall product development process because it is typically not owned by a single function or organization within a firm. Additionally, technology integration is a competency which is inherently about creating linkages between functions that have historically been very separated.

Iansiti, who focuses on the selection aspect, makes a similar observation when he points out that technology integration is a bridge that links the world of technology development, which we often call research, to the world of product and manufacturing process development (Iansiti 1997). He suggests that research has focused on either how we conduct effective research to create technological possibilities or on how we can execute effective product and manufacturing process development, but not on the linkage between the two. Technology integration, as an explicit function, does not necessarily reside within the domain of the research, engineering, or manufacturing organizations of a firm. In essence, technology integration "falls between the cracks" of technological research, and product and process development and is thus not well accounted for in the literature.

Despite neglecting technology integration as a specific competency, much effort has been expended at studying its outcome - a successful new product. Ever since Schumpeter introduced the term "creative destruction" as a means to characterize innovation from an economic perspective (Schumpeter 1942), innovation and new product development have been studied in great detail to both characterize it as a disciplined process and to identify those factors which promote its success. Some of my colleagues might argue that technology integration *is* the process of innovation and new product development. However, I chose to think of technology integration as narrower than the broader context of general innovation and product development. For those that insist that technology integration is nothing more that product development and innovation, it is still useful to use the definition introduced in Chapter 2 as a lens through which to view the research on innovation. Through this filter, we can begin to glean the competencies and practices that specifically promote the ability to select and link disparate technologies together into a product.

Product Development and Innovation

Brown and Eisenhardt have published a very extensive summary of past and present research that has been conducted in the broad fields of innovation and new product development (Brown and Eisenhardt 1995). The authors have taken this work and have synthesized a model of successful innovation and new product development that integrates these various perspectives. I will use this model to explore insights into technology integration that are embodied in the understanding of product development and innovation.

Brown and Eisenhardt identified three important streams of research that characterize fundamental conclusions about successful innovation and new product development. They suggest that these streams refer to successful product development as:

1. A rational plan,
2. A communication web, and
3. A disciplined problem solving process.

Rational Plan:

The rational plan view of product development suggests that success stems from

a) the careful planning of a superior product for an attractive market, and,
b) the execution of that plan by a competent and well-coordinated cross-functional team that operates with
c) the blessings of senior management.

Research studies within this context focus on relating many different independent factors to the financial success of the new product or service. One of the earliest studies in this research stream showed that successful products from a market perspective resulted from a strong understanding of the market and user needs rather than a deep understanding the underlying technology. Subsequent studies have also documented the importance of linking technology to the market context to achieve successful products. Cross functional teams and skills are also highlighted by the rational plan concept as being important to creating successful products.

The implications for technology integration from the research stream characterized as a rational plan clearly show that the technologies that ultimately get combined into the product must first be thought of in the context of the market. Once a product concept and its constituent technologies has been envisioned to be a success in the market, significant utilization of cross-functional skills and teams is required to turn the vision into reality.

Communication Web

This stream of research is based on the fundamental work of Tom Allen where it is shown that communication among project team members and outsiders stimulates the performance and success of product development teams (Allen 1971; Allen 1977). Allen identified the importance of gatekeepers to the success of innovation. A gatekeeper is a high-performing individual that is the principle conduit for the team's contact and access to people and information external to their organization. Ancona and Caldwell delved deeper into the specific external communication and interaction activities of high performance product development teams and found that specific types of activities (ambassadorial, task-coordination, technical scouting) rather than frequency of external communication was a predictor of success (Ancona and Caldwell 1992). Internal communication within teams was also identified as promoting product development success in studies performed by Ancona and Caldwell (Ancona and Caldwell 1992). Dougherty identified that the "thought worlds" of each of the functional departments need to be brought together into a parallel, iterative, interactive manner (Dougherty 1990). High internal communication increases the quantity and variety of information that the team uses to develop and implement the new product idea.

Viewing product development and innovation as a web of both internal and external communication suggests two implications for technology integration. First, access to external information including both technological and market opportunities should lead to greater success. Second, internal cross-functional interaction that brings together the different perspectives of the technical disciplines along with market perspectives should lead to superior technology integration.

Disciplined Problem Solving

This stream of research views product development and innovation as a disciplined problem solving process at the project level balanced with a clear product vision developed at the executive level. This view also suggests that successful product development is enhanced by the use of cross-functional teams which are organized according to the needs of the development project. It clearly places greater emphasis on the process of product development compared to the communication web and rational plan perspectives.

Early work in this research stream studied successful Japanese product development projects. Imai et al found six interfirm factors and one external linkage to be key for product development success (Imai, Nonaka et al. 1985). Top management provided an overall strategic direction and vision for the product that was derived from and consistent with their knowledge of the market environment and the firm's strengths and weaknesses.

Management also provided subtle control rather than acting purely in an advisory role. Self-organizing teams of cross-functional make-up were utilized. The phases of the product development process were conducted in an overlapping and parallel manner as opposed to a sequential process. Learning was also conducted across functions and across levels. This learning was captured through its incorporation into the institutional memory rather than remaining within the knowledge of the individuals. The external key success factor was the extensive use of suppliers to provide knowledge and capabilities that were outside of the boundaries of the firm doing the product development.

Later research extended and validated this early work through studies of major car development projects (Clark and Fujimoto 1991). These investigators also presented support for the use of extensive supplier networks, the use of overlapping product development phases, communication, and the use of cross-functional teams. They also identified the contributions to success from heavyweight team leaders who both coordinated the activities of the product development teams, and also served as the link to senior management and to the overall vision for the product.

Eisenhardt and Tabrizi looked at the speed of product development in the computer industry and found teams that used an experiential, iterative process with frequent testing and milestones were more successful as measured by speed (Eisenhardt and Tabrizi 1995). They also identified that supplier involvement, the use of CAD tools, overlapping product development phases, and extensive planning can inhibit the speed of new product development if they are not carefully employed.

This stream of research continues to support the notion that cross-functional teams, internal/external communication, product vision within a market context, are all factors which promote technology integration. The additional factor that is found here and not in the other two research streams is the utilization of an approach that incorporates experiential iteration. The use of software tools and system knowledge enables a firm to employ an educated trial and error strategy which rapidly converges the design to the optimum.

Technology Integration from a Project-Level Perspective

Marco Iansiti has been particularly concerned with understanding technology integration at the product level in environments characterized by high uncertainty. His early work looked at the computer mainframe industry where component technologies were steadily changing within a relatively stable market context (Iansiti and Clark 1994; Iansiti 1995). In later work, Iansiti has looked at the workstation and internet industries where both the technological possibilities and the market needs are highly uncertain (Iansiti 1995; Iansiti 1997). Iansiti particularly stresses the selection aspect of the definition of technology integration introduced in Chapter 2. He defines technology integration to be the selection of technological possibilities within the context of the marketplace to produce a product that makes business sense. Technology integration from this viewpoint is the bridge that links the possibilities created by the R&D process to the product development process. He argues that the technology choices not only drive product performance (the effectiveness of the product development process), but they also drive the efficiency of the product development process. Iansiti summarizes his findings by stating:

> *"...a good technology integration process should proactively induce a broad and informed approach to decision making and problem solving. The process should emphasize the experimentation aimed at the early generation of knowledge, about the potential impact of novel approaches on the application context. It should manage the retention of knowledge through past experience. The knowledge retained through experience and generated by experimentation should be integrated by a dedicated group of individuals charged with making technology choices with influence over the relevant application context. The choices should be kept open until informed decisions can be made, thereby avoiding premature commitments."*

The key factors which promote technology integration in the industries that Iansiti studied are:

Technology Integration Function: This function defines the architecture of the product. It is accomplished with a dedicated individual or a dedicated group along with the investment of significant resources to specifically evaluate the technical possibilities and to make the selection from those possibilities such that there is coherency between the technology, the product concept, the production systems, and the marketplace. The people who fill this role have particularly broad backgrounds in understanding both business and technology issues, as well as a strong understanding of the customer.

Prototyping: Development projects which yielded higher performing products utilized rapid prototyping and simulation to analyze the implementation of various system-level choices. Better integration resulted from more frequent trial-and-error prototypes that were tested in hardware or through software simulations.

Accumulation and Application of System Knowledge: Knowledge gained from the technology integration of one project is carried forward so that it can be used to effectively guide the decisions on the next product development project. This knowledge retention and transference is primarily accomplished through using the same people on subsequent projects, particularly those performing the technology integration function.

Delaying Product Design Freeze: The period of time where component technologies are evaluated and where various combinations are tested together in a product architecture is a window of opportunity to obtain the best fit between what is technically feasible and what will be successful in the marketplace. More successful technology integration was achieved by those firms able to employ a flexible process that kept this window open as long as possible before freezing the final design. This does not mean that they lengthened the overall development process commensurate with enlarging this window of opportunity. The successful firms skillfully identified those elements of the product design that needed to be frozen early on and those elements that should and could remain flexible to fairly late in the process.

Iansiti claims that the reason these factors dramatically effect the ability to integrate technologies into a product stems from the complexity of the products and the uncertainty of the industries that he studied. He asserts that since the semiconductor and mainframe computer environments are characterized by high technological uncertainty, making the selection of the technologies to integrate into the product is much more of a challenge than for those industries in a stable environment. He extends his conclusion by stating that if the technological environment is relatively mature and stable, then the selection of the technical approach is not a major challenge and differences in product performance and project efficiency are due to project mismanagement, and "coordination and ***integration*** problems" (emphasis added) (Iansiti 1997). With this statement Iansiti is acknowledging that the process that follows the selection between technological possibilities does involve integration and does have an effect on the performance of the resulting product. He is merely arguing that in certain environments, such as those that exhibit significant uncertainty, the selection part of technology integration possibly plays a more dominate role than the latter part of this process. Thus, I argue that the broader definition of technology integration that I introduced in Chapter 2, is generally more applicable since it includes the part of the product development process where the selected technology components are combined together into the product. Furthermore, I will show in a case study of the air conditioner industry, presented in Chapter 5, that even in very stable and mature industries that very significant differences can exist in technological integration capability and strategy.

Disruptive and Sustaining Innovations

Posing the following question leads to some additional insights into the key factors of innovation that affect technology integration: *Can a firm that is good at innovation in general, and at technology integration specifically, integrate almost any new or existing technology into its product?* The answer is not clear. We would expect an automobile manufacturer to be able to integrate a new combustion chamber shape into its gasoline powered engines. But what about the ability to successfully integrate a new propulsion technology such as electric drives into the automobile? This answer is not as clear. What about the ability of a children's clothes manufacturer to integrate wireless communications technology into their coats so that parents would know the whereabouts of their children? We might be more skeptical, but still uncertain in this case. So then, what is it about the nature of the technology that suggests why one technology might be easily integrated by a firm and why another technology would present a nearly impossible challenge to that same firm? Is it the size of the technology hurdle, is it the newness of the idea, is it the degree of difference with the existing competencies of the firm?

Christensen has explored this issue in significant detail in a forthcoming book where the notion of the technology as acting to either sustain or disrupt the performance of a product is central to answering these questions. Christensen and Rosenbloom have introduced the framework of a "value network" to explain the differentiation between sustaining and disruptive technologies (Christensen and Rosenbloom 1995).

A value network is a technological paradigm which defines the context in which the firm solves customer problems by using resources and associations both inside and outside the firm. Structurally, the value network is the entire value chain including suppliers, customers, and the organizations internal to the firm. In practice, a value network defines how the firm identifies and satisfies customer needs, procures inputs, reacts to competitors and strives for profit (Christensen 1997). This paradigm acts as a lens through which the firm views all possible opportunities for new technologies and new products. If a technology fits this paradigm, then it is likely to be recognized and incorporated into the product regardless of the degree of the technical hurdle. On the other hand, if the potential technology does not make sense within the paradigm, then it is unlikely that the firm will recognize the opportunity to utilize the innovation, regardless of its level of complexity. Christensen suggests that the rank ordering of the product performance characteristics by the firm's traditional customer is a strong manifestation of this value network or paradigm. If the technology reinforces and improves the currently accepted measures of product performance (S_1, S_2, S_3 in Figure 3.1) then it is likely to be recognized and adopted by the firm. These technological advances are referred to as "sustaining" since they sustain the system of use of the product. If the technology affects performance measures that are not relevant to the customer (and to the firm) then it is unlikely that the firm will integrate the new technology into its product. The technology must be adopted by a different "value network" where its performance improvement ability makes sense and fits the paradigm (D_1, D_2 in Figure 3.1). The unfortunate reality for existing firms is that new technologies that they initially reject are improved in these alternate value networks to the point where the product performance now fits within the value network of the incumbent firm. When this happens, more often than not, firms in the alternate value network begin to rapidly steal market share from the firm that is stuck in previous value network. The technology is thus ultimately "disruptive" to the success of the original firm.

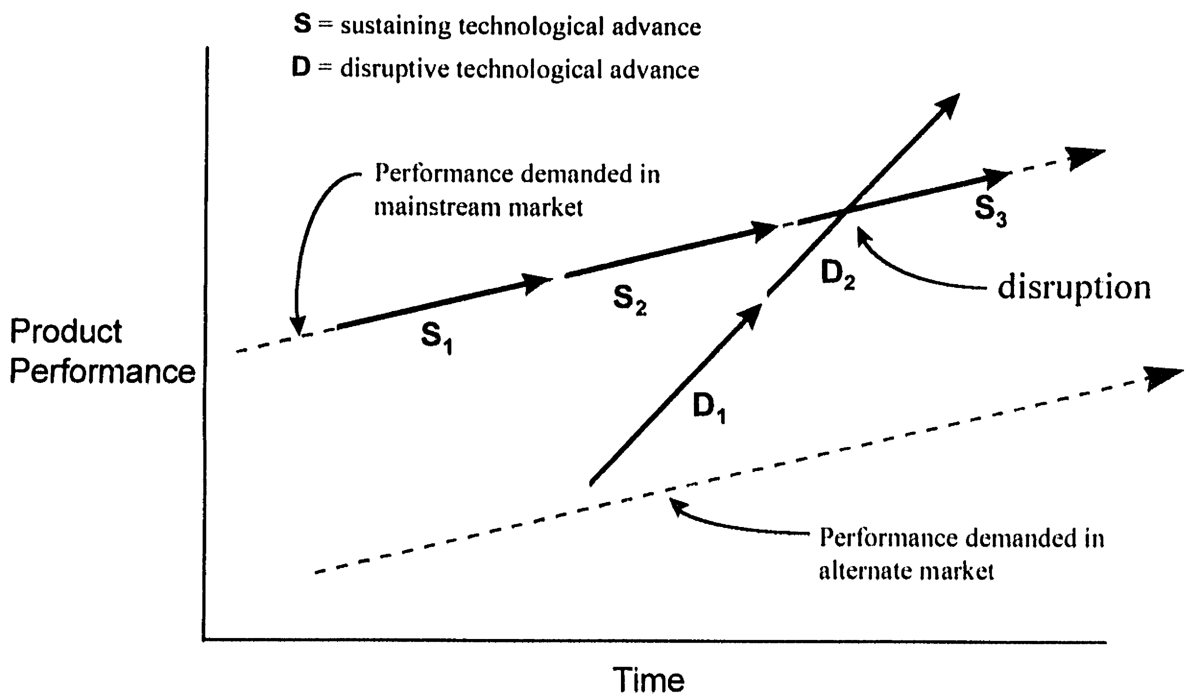

Figure 3.1. Technology improvement in an alternate value network can disrupt a firm following a series of sustaining innovations.

Christensen illustrates this phenomena with a case from the excavation equipment industry in the US. Prior to the 1920's most excavation equipment was powered by steam, hence the term - steam shovel. Steam was used to move the cables that actuated the buckets of the excavator. In the 1920's the radical idea of gasoline powered engines arrived on the scene as a potentially viable technology to integrate into excavators. The gasoline engines along with a system of gearing, clutches, and drums provided a cheaper, faster, more reliable means to move the actuating cables which translated to more reliable, cheaper, and faster means to move earth - key measures of performance in the excavator value network. Since the new gasoline engine technology was sustaining in its nature to improve the recognized measures of product performance, it was readily adopted by almost all of the industry. Although it was a fairly radical new technology, 23 of the 25 largest firms at the time successfully integrated gasoline engines into its products.

In the late 1940's and 1950's hydraulic actuation technology appeared which was equally as radical as the introduction of the gasoline engine. Initially, hydraulic actuation that replaced cables was significantly inferior in terms of its range of motion and the capacity of earth that could be moved. Cable actuation remained superior in terms of range of motion and capacity which were recognized as the key measures of performance. Thus, this technology did not fit within the existing value network paradigm of the excavator manufacturers at that time, and they rejected the integration of hydraulics into their products.

Hydraulic actuation did make sense in the value network for excavators used by small contractors to dig trenches. Called backhoes, these hydraulic excavators were attached to industrial and farm tractors to replace the hand digging of relatively small trenches in new residential developments. The product performance requirements in this value network were narrow bucket sizes, and maneuverability - quite different from cable actuated machines, but quite appropriate for hydraulics. Through the 1950's and 1960's, hydraulic actuated excavators increased in both size and in improved range of motion to the point where they equaled the requirements of the large mainstream excavation market. As the capacity of hydraulic excavators increased, manufacturers that had pioneered the small hydraulic excavators increasingly gained market share at the expense of the manufacturers of traditional, large capacity cable actuated equipment. This new technology from a different value network was so disruptive to the traditional manufacturers of cable actuated equipment, only 4 of the 30 firms that were in the cable actuated excavator market in the 1970's survived the transition to hydraulics.

I introduce this lengthy example from Christensen's work to illustrate that there are factors inherent in the technology that will greatly affect the ability of a firm to integrate it into its products. Those technologies that are recognized within the firm's existing value network will be much easier to integrate than those that do not sustain the performance of the product as measured by the parameters defined by the value network. The difference between this factor and the other factors highlighted in the earlier discussion of innovation, is that the degree of sustainment of the technology is beyond the control and influence of management, yet it may be of equal or greater importance than those success factors that can be controlled.

Product Platforms

Marc Meyer and Alvin Lehnerd have suggested that most companies approach technology integration and product development sequentially one product at a time while failing to exploit commonality, compatibility, standardization, and modularity across different products and product lines (Meyer and Lehnerd 1997). They propose the concept of product platforms as a way of thinking and a way of developing products that enable numerous products and derivatives to be developed rapidly and efficiently. Meyer and Lehnerd define a product platform as "*.....a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced.*" They argue that the product architecture, as defined by the integration of component technologies, should be done from a platform perspective that makes the architecture as common across many different products as possible. This utilizes product design and manufacturing commonality to create new products faster, and at lower cost than unique sequential product-by-product development efforts. Commonality of subsystems not only makes the design process more efficient, but it enables greater manufacturing and procurement economies which further contribute to lowering product costs. The benefits of this approach seem fairly obvious, but most firms, however, seek to engineer and build the perfect product for each customer group which leads them away from product and subsystem commonality.

Meyer and Lehnerd explain the product platform strategy and its associated benefits can be achieved by following a "composite design" process. Composite design is defined as "the identification, analysis on a function and cost basis, selection, and integration of subsystems and interfaces into products that harmonize the form and function of the overall system." This is essentially the definition of technology integration that we adopted in Chapter 2. Meyer and Lehnerd make an important distinction that the majority of the technology integration effort should be done at the product architecture level in a manner that provides "degrees of freedom" that can be exploited later to develop derivative products rapidly and at far lower cost than the traditional product-by-product strategy.

Meyer and Lehnerd use the strategy pursued by Black & Decker in the 1970's redesign of their complete line of power tools to demonstrate the advantage that a product platform strategy can provide. A key subsystem of hand power tools is the motor which had been traditionally designed and manufactured differently at Black & Decker for each power tool. The composite design methodology led Black & Decker to modularize and standardize the motor design to be common across all of its power tools. The motor diameter and interfaces were made common for all power tool types and models. The length of the motor was the only dimension that changed as the power of the motor was increased. The design simply required a change in the number of common-sized armature plates to scale the motor to any desired wattage. The annual savings of this motor design were $1.28M in 1974 which resulted from a 39% reduction in unit cost. The motor design and the synergies created with the component redesigns enabled Black & Decker to efficiently introduce a family of power tools that ranged from low-cost entry level products (a drill for under $10 in 1973) to higher margin, higher performance products utilizing the same product platforms and many common subsystems. Black & Decker's resulting business success in power tools was stunning. Unable to compete on price, manufacturers such as Stanley, Skil, Sunbeam, General Electric and others left the consumer power tool business.

Chapter 4 - Successful Technology Integration Strategy and Process

The discussion presented in the previous chapters leads to the important notion that technology integration is less about the inherent technical competency of a firm and more about the firm's ability to strategically select a set of technologies and to very efficiently and effectively combine those technologies into a product. A firm must blend the technological possibilities with strategic business opportunities to create an overall business/technology strategy which will be both technically and financially successful. Once the strategic framework is established, technology integration must be facilitated by a set of processes which effectively and efficiently enable the product to be created. Competency in the constituent technologies of the product is important and necessary, but not sufficient to achieve superior technology integration.

The entire picture of technology integration is thus a combination of a coherent winning strategy and effective operational processes. This notion parallels Porter's recent thoughts where he argues that operational effectiveness is necessary, but not sufficient for success (Porter 1996; Porter 1997). Long-term success does not come from competing on the basis of operational effectiveness, and hence, this is not strategy. Strategy, he asserts, is the process of making tradeoffs to establish a system of competencies and positioning that is unique from the competition and will provide a durable competitive advantage. Successful technology integration at the process level is part of Porter's notion of operational effectiveness while technology integration at the business strategy level is consistent with his idea of strategy.

Technology Integration as Business Strategy

Technology integration as strategy can be best understood from the perspective that the overall strategy of a firm is a hierarchy of increasingly focused constituent strategies.[2] At the highest level, the overall business strategy defines how the firm will create value by identifying particular markets to be served, product types to be offered and the positioning of the firm within the industry to achieve superior results. Technology integration at this level is principally focused on the process whereby a firm evaluates and selects from various technological options to support a business strategy and to also influence the adoption of the most successful business strategy. For example, a firm which owns proprietary, low cost and high volume production technologies could use these to develop a price leadership business strategy. Alternately, a firm which decides that the industry environment dictates that a lowest price strategy is its only avenue for success, might select the lowest-cost means of production from the set of all production technologies available to it. At the business strategy level, technology integration (with emphasis on the selection of technological possibilities) must work synergistically to create an overall winning strategy that ties together business opportunities with specific technology and product design options.

The top level business strategy is then supported by a series of more detailed strategies that might prescribe the marketing, financial, distribution, and product line specific strategies. Technology integration at this level is again both an enabler and an outcome of these operational strategies. Product architecture is identified at this level through the selection of specific technologies and features which will be incorporated into the product. For example, a platform strategy for product development and product line management may be adopted here to be synergistic with the cost and product line complexity requirements of the business strategy.

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[2] I gratefully acknowledge Dr. Robert J. Hermann for his suggestion of a strategic hierarchy to explain the flow-down of technology integration from the firm business strategy.

The lowest levels of the hierarchy contain the specific strategies for each of the products and their constituent component technologies. This is the tactical level where the product architecture is executed to create the individual products in the product line. Technology integration still involves choices here also, but at the specific and detailed level of component designs and manufacturing processes. Provided that strong synergy and coherency has been maintained throughout the hierarchy of the business and technology integration strategy formulation, the teams should have a very clear understanding of how to make these final tradeoffs and component process selections.

Successful technology integration, therefore, begins with an effective business strategy that accounts for the technological possibilities that help shape the competitive positioning desired by a firm. It further continues with a series of increasingly detailed supporting strategies which define the technological selections from the product architecture level down to the component level. Technology integration from a strategic perspective will be most successful when a strong coherency and synergy is maintained between the business and technology strategies as they are derived in increasing detail extending from the overarching firm strategy.

Technology Integration Through Operational Effectiveness

The operational aspects of technology integration are somewhat easier to identify and understand since a great deal of extensive study on innovation and product development has been conducted from this perspective. Most of the foundations of technology integration discussed in Chapter 3 are processes and behaviors which promote better technology integration at the tactical level. Provided that there is a linkage and coherency between these tactics and the higher level strategies, focusing on these behaviors and practices will greatly and positively impact the overall outcome of the technology integration process.

We can thus use this research to build a framework to understand the key factors which drive successful technology integration processes. This framework is presented from the perspective of a manager within a firm who is faced with organizational, process, and resource choices that must be made to integrate component technologies together into a product. This perspective suggests that the framework must account for the sets of factors that are either within or outside of the manager's control. I assume that the manager has direct or indirect control over those factors which are concerned with the detailed strategy, structure, people, and processes within the firm. At this operational level, I assume that the manager has little to no control over the external environmental conditions which establish the context for the firm-specific factors and little opportunity in the near term to influence the overall firm's business strategy. The manager must understand, however, how these external conditions effect the relative importance of the factors and decisions under their control.

For usability and simplicity, I have tried to focus only on the significant principle factors which promote integration. As we learned from the literature, numerous factors can have some effect on innovation in general, and on technology integration specifically. My goal here is to not identify every factor which affects technology integration, but only to highlight the small number of principle factors which are both recognizable and actionable by managers of a firm.

Management Actions to Promote Technology Integration

This framework of management controllable and environmental factors was developed through a combination of literature reviews and field interviews with experts in technology and systems integration. A robust proof of these factors and their particular influence is beyond the scope of this thesis. However, the degree of consistency among the interview subjects and between their opinion and the published literature is encouraging and suggests that this framework is fundamentally correct, although it may not be complete.

During a series of ten interviews, I presented the definition of technology integration discussed in Chapter 2 and then proceeded to question the subjects regarding what they believed to be the key factors which promoted the success of technology integration. I asked them to utilize their previous experience with successful and unsuccessful projects as the basis for their answers. From their responses, and from the research studies discussed in Chapter 3, several clusters of thinking emerged that captured the thoughts of both the researchers and the interview subjects.

Successful technology integration is driven by managerial actions and decisions which focus on reinforcing three basic behaviors: 1) making and strengthening linkages, 2) preventing biases, and 3) promoting iteration. Table 4.1 highlights the factors which promote each of these three behaviors. Furthermore, I suggest that the relative importance and means to achieve these behaviors varies according to the environmental factors which describe 1) the uncertainty of the technology and market, 2) the complexity of the product system, and 3) the degree to which the technologies are sustaining or disruptive.

Table 4.1. Management-controllable factors which promote successful technology integration.

Make & Strengthen Linkages	Prevent Biases	Promote Iteration
• Existence of technology integration function	• Sufficient access to potential technologies	• Support for failure (vs. incrimination)
• Utilize IPD teams	• Outsourcing of components	• Use of simulation and modeling
• Physical team co-location	• Outsourcing of technology development	• Frequent model updates and improvements
• Product vs. Functional organizational structure	• Participation of new people	• Avoid paralysis by analysis
• Strong participation of marketing	• Relatively equal power between technical disciplines	

Making and Strengthening Linkages

It should not be surprising that linkages are important to an activity whose goal is to integrate various parts into a functioning whole. Better quality decisions will be made when information concerning all of the constituencies of the product are considered. The process of knitting together the selected technological components will be more effective and efficient when all of the engineering, manufacturing, and product support functions are brought together. The linkages are what cause the appropriate people and information to be brought together. The studies by Iansiti and Clark and Fujimoto, suggest that these linkages can be broadly characterized into two categories, technological links and business links. The first category includes those linkages which bring together the technical disciplines, engineers, and the components together to enable the product to be designed and manufactured. The second category of linkages are those that make sure there is a coherency between the product architecture, the needs and desires of the users, and the positioning of the product relative to competitors. The behavior of making and strengthening linkages can be supported by management actions and decisions which ensure that the appropriate people and information are connected.

Technology Integration Function: Dedicating a specific person or group of people to evaluate technological possibilities and product architectures against the context of the market promotes a successful product outcome, and lessens the probability for a technically elegant product that fails to be accepted by users. This role is generally filled by experienced people with broad technology and business backgrounds and familiarity with the expectations and needs of the customer. Iansiti found this function to be most effective when it was fulfilled by people outside of the product development team, though Clark & Fujimoto, and Katz & Allen suggest that a strong project team leader can also provide the coherency and linkage to the business issues. Nearly every interview subject I spoke with raised this as being the most important factor for successful technology integration. They further suggested that, in their experience, it was senior management who was most successful at creating the strategic linkage between technological possibilities and the market environment.

Integrated Product Development: The use of integrated product development teams is a well established best practice for product development (Clark and Wheelwright 1993). It is also key for strengthening both business and technological linkages which support technology integration. A multifunctional team is more likely to select and knit the component technologies together into a higher performing product if experts in all of the technical disciplines participate in the process.

Co-location: Co-location of the functions that participate in the design process is likely to promote a superior integrated product since it encourages spontaneous and informal interaction of the various individuals responsible for the integration (Allen 1971). The interview subjects all agreed that utilization of cross-functional teams and their co-location was a given and almost a taken-for-granted way of doing product development today.

Product versus Functional Organization Structure: Since structure strongly influences behavior, the organization of the firm's technical staff around products or product lines is likely to promote greater interaction of the various technical disciplines that comprise the product (Roberts 1979; Chester 1994; Goodman and Lawless 1994). The product organizational structure promotes a constant vision on creating a superior product rather than creating superior technology.

Participation by Marketing: The participation of marketing in making key decisions about the technological components of the product is extremely important since they are the primary link to the customer (Roberts 1979; Clark and Fujimoto 1991; Clark and Wheelwright 1993; Iansiti 1995; Iansiti 1997). Better decisions concerning the product architecture and component technologies will be made when there is a strong voice of the customer considered in the process. The participation of marketing as a factor in promoting making and strengthening linkages could be assumed to be part of the technology integration and/or IPD factors. I have broken it out as an explicit factor because of its importance to technology integration.

Preventing Biases

The best decisions regarding which technological components to use and how to combine them into a product can only be made in an environment that is free of biases and where there is freedom, access, and incentive to explore all possible solutions to meeting customer needs. Management must prevent the individual organizations with the relative depth of skill and understanding for the component technologies from biasing the product architecture toward the technology which has the strongest position within their organization (Leonard-Barton 1992). Furthermore, Leonard Barton has shown that the core competencies that are critical to a firm's success (e.g. (Prahalad and Hamel 1990)) also have a downside in that they add rigidity to a firm and severely inhibit innovation and technological opportunities outside of the paradigm created by their core competencies (Leonard-Barton 1992). Finally, management must actively balance the technical and business perspectives brought together in defining the product architecture so that neither inappropriately dominates the product design.

Outsourcing: All other things being equal, a firm that outsources more of its components and/or technology development will have a culture that is more predisposed to considering options that come from outside of the firm. In the extreme case of a firm that outsources 100% of its components, there is no internal bias towards a particular solution that uses an in-house produced component. Furthermore, outsourcing considerably expands the realm of technological candidates beyond what a firm could provide internally.

Participation of New People: The introduction of new people outside of any previous product development teams will bring new ideas and perspectives to the process and help the team from getting stuck in the paradigm defined by the previous process (Janis 1971). Katz has shown that innovation effectiveness of teams with intermediate terms of membership outperformed those teams that were together with the same people for very short or for very long periods of time (Katz 1982). A large systems integrator remarked that hiring new people was their principle mechanism for learning about new technologies.

Equal Power of Technical Disciplines: Firms which have a technical competency that is considerably stronger and/or deeper than other component technologies will favor solutions where the dominate technology is the driver. This is just a restatement of the adage: "If I have a hammer, then everything looks like a nail to me." Iansiti illustrates this bias with the description of how two different computer manufacturers solved the same problem of the buckling of ceramic and metal layered substrates by enabling integrated circuits to be attached to printed circuit boards (Iansiti 1997). One company, which had a dominant competency in materials science, spent considerable time and effort iterating through a series of solutions which adjusted the material composition of the substrate. This materials science solution was not very robust since minor changes to the substrate manufacturing process caused the buckling problem to reoccur. The second computer manufacturer did not have a bias to a single technical discipline. A multidisciplinary technology integration group was assigned to solve the problem. The solution they chose was achieved faster, with fewer resources, and resulted in a very robust fix for the problem. Thus the effectiveness of the technical integration should favor firms where the technical disciplines have relatively equal power and influence over major product architecture decisions. Several of the experts that I interviewed identified that the role of the project team leader and/or systems integrator was to prevent this specific bias from occurring if one of the technical disciplines was trying to inappropriately drive the design.

Promoting Iteration

Achieving a product design that makes the optimal tradeoffs between technological and architectural possibilities is difficult, at best, even for products of minimal complexity. This results from the human mind having very limited capacity for comprehending the implications of interactions beyond simple input/output relationships (Forrester 1961; Sterman 1994). We overcome these limitations by iteratively testing ideas and designs which successively bring us closer to the optimal design (Homer 1996). Building physical prototypes which can be evaluated from both the technical and market perspectives is one embodiment of the iterative process. Thus, the more management directs and encourages the use of fast iteration and prototyping, the better integration between the components will be achieved.

The acceleration in availability and performance of low-cost computing capability is increasing the use of simulations to replace all or part of the sequence of building physical prototypes. Computer simulation increasingly provides a method for testing many different combinations of system components in a short period of time and usually at a far lower cost than can be achieved through the use of physical prototypes.

As Iansiti and Eisenhardt point out, iteration is extremely important in environments characterized by a high degree of uncertainty (Eisenhardt and Tabrizi 1995; Iansiti 1995). If the industry has not adopted a dominant design, there are many more potential approaches to meeting customer requirements and thus many more potential product designs that need to be evaluated (Utterback 1994).

All of the systems and technology integration experts that were interviewed identified this factor as critical to effective and efficient technology integration. One remarked that he coached his teams to pick a set of decent technologies (unlikely the best technologies) and then to proceed with the trial-and-error process of figuring out how to best merge them.

Simulation and Modeling: Firms that have a greater utilization and sophistication of modeling are likely to achieve superior integration of the product components. The wok of Eisenhardt and Tabrizi suggest, however, that care must be taken to ensure that the modeling and simulation software packages remain as tools to support the design iteration and do not themselves become the focus of considerable development effort to overcome incompatibilities (Eisenhardt and Tabrizi 1995).

Culture Supporting Failure: By its nature, the process of prototyping and iteration will produce designs and architectures that are "failures" in that they do not provide the optimal solution. A firm with a culture that penalizes or otherwise inhibits the trial of ideas that turn out to be failures will ultimately try fewer designs which have the opportunity to push the performance of the product closer to its limit. This is not to say that a firm should waste time and resources by conducting a detailed analysis on every idea, regardless of how bizarre it might appear at first. Rather, the firm needs to use a process that treats all ideas as possibilities in the beginning, but quickly identifies those with promise that deserve more careful analysis. Tom Peters characterizes this by exhorting firms to "learn to fail fast" (Peters).

Frequent Model Introductions: All other things being equal, a firm that produces more frequent model introductions will integrate technology better. The more often a firm introduces a new or improved model, the more often the firm goes through the technology integration process. Since product development has often been characterized as a learning process, the more often that a firm does it, the better the firm will become at doing it.

Environmental Factors

The preceding discussion focused on factors that are directly or indirectly under the control of the management of a firm and that strongly influence technical integration capability. There is a second set of factors which are not under control of the firm management, but are just as important for determining the success of technology integration. I refer to these as environmental factors because they describe key attributes of the business and technical environment external to the firm that greatly influence the success of the technology integration process internal to a firm.

Technological and Market Uncertainty

Environments where technological possibilities are rapidly changing and/or environments where the requirements of the market are unclear and changing create uncertainty for formulating a product strategy. This stresses the technology integration process because the definition of what constitutes a better product is both elusive and changing. There are simply more technological possibilities, more information, and more people that must be brought into the process. This environment will place a greater emphasis on all three of the behaviors discussed above. In particular, the work of Iansiti and Eisenhardt suggest that product design flexibility and iteration are extremely important in this environment (Eisenhardt and Tabrizi 1995; Iansiti 1995). Trying lots of potential product configurations (real or simulated) while delaying the final configuration decision until as close as possible to market introduction is a lesson from the computer industry that likely has general applicability.

Product System Complexity

The complexity of the product when viewed from a systems perspective will directly effect the ease of technology integration. Complexity can be described along the dimensions of the complexity of the component interactions and the modularity of the component technologies. If the overall product system is complex due to many different components interacting in subtle and complex ways, then the integration of the technological components will be much more difficult. For example, integrating together the functional components of a computer operating system, such as Windows 95, or an enterprise business software system, such as SAP, will be much more difficult than integrating the functional components of a simple utility program. System complexity is also greatly affected by the modularity of the constituent component technologies. I define modularity as the degree to which the interface between the components are documented, stable, and understood. For example, an Intel-based desktop computer is a fairly complex system from a functional standpoint. Yet, the interfaces of the components such as the disk drives, the motherboard, the power supplies, the graphics system, etc. are very well documented and defined. This high degree of modularity makes it easier for manufacturers to build computers by integrating the components. A recent article on the components comprising a laptop computer identified over twenty-four principle manufacturers of ten major components used by the laptop manufacturers. Modularity certainly makes it easier to integrate components into a product system, however, it does eliminate decisions that can have a dramatic effect on overall performance.

Sustaining vs. Disruptive Technology

The discussion in Chapter 3 highlighted Christensen's work which shows that certain technologies are much more difficult than others for firms to adapt to and integrate into their products. Technologies that sustained the performance of the product within the existing value network will be much easier to integrate than technologies which do not make immediate sense for inclusion into the product design.

Chapter 5 - Technology Integration Strategy in Residential Central Air Conditioners

Residential central air conditioners provide an opportunity for studying technology integration in a relatively mature market and under a fairly stable technology environment. A mature industry where a dominant product design is well established, where markets and technology change incrementally, where competitors are well-established, and where everyone has equal access to component technologies, serves to highlight the impact that different technology integration strategies can have. Viewed another way, we cannot attribute the differences in relative success of the industry players to superior knowledge or better access to key technologies. We can therefore assume that differences in firm performance must be due to their business market strategy and their approach to integrating component technologies to form the product system. We can thus test the validity of our claim in the previous chapter that successful technology integration must exhibit a strong linkage to, and coherency with, the overall business strategy.

The two largest residential central air conditioning competitors,[3] Carrier and Goodman Manufacturing, were studied to understand their technology integration approaches and business strategies. We will see that, although the products are not differentiated in performance, features, and components, very different approaches to integrating the component technologies are taken by each firm. Supporting the discussion in the last chapter on the strategic nature of technology integration, we will see that the different technology integration approaches taken by Carrier and Goodman are consistent with the different business strategies that they each pursue.

[3] Based on 1996 unit volume sales

Industry Overview

The US market for central air conditioners is served almost entirely by domestic producers which shipped just over 4.5 million units in 1996.[4] Six manufacturers, shown in Figure 5.1, accounted for 81% of these shipments with the two market share leaders, Carrier and Goodman, accounting for 37% of total industry sales. The volume of unit sales has been growing, achieving a total growth of 57% from 1991 through 1996.

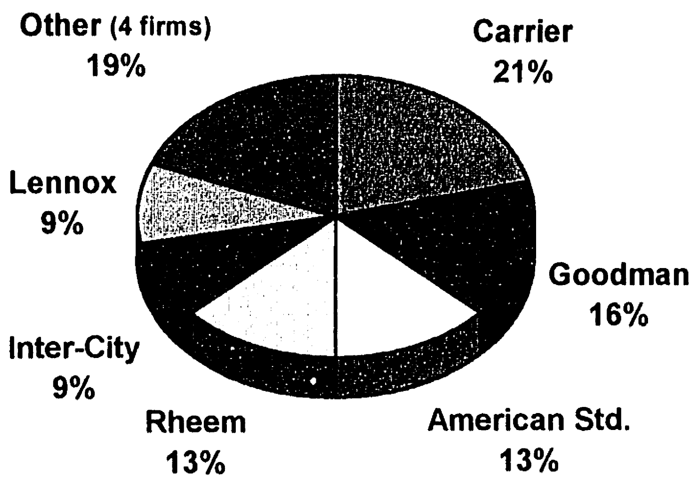

Figure 5.1 Residential Central Air Conditioning Market Share - 1996
(source: Appliance Manufacturer, 1997)

Manufacturers distribute central air conditioner products through independent distributors, dealers, and contractors which sell and install the units in the homeowner and home builder markets. Competition is principally based on price, efficiency, reliability/quality, and dealer/contractor competency. There is comparatively little opportunity to differentiate these products based on other features since they all perform the same function in the same way, and are installed to be out-of-sight, and out-of-mind of the end-user.

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[4] 1997 Market Profile, Appliance Manufacturer, 1997

Energy efficiency is not a significant competitive driver due to federal regulations and the focus on initial costs. The National Appliance Energy Conservation Act mandated that all air conditioners, manufactured after January 1, 1992, must have a seasonal energy efficiency ratio (SEER[5]) of at least 10. Current central air conditioning units range in efficiency from 10 to 17 SEER, with higher efficiencies commensurate with higher prices because larger heat exchangers and higher performance compressors are required. The greater cost can be paid back through lower energy consumption depending upon the climate and the cooling desires of the owner, however, most US homeowners focus on the purchase price of the unit after noting that it meets the federally mandated minimum efficiency rating. Price sensitivity and uncertainties over the length of stay in a home lead many homeowners to avoid the higher efficiency units and to purchase air conditioners with an SEER of 10.

Similarly, builders in the residential new construction market, which focus on providing the most features for the lowest initial cost, utilize the 10 SEER units almost exclusively except in the few more expensive homes. Thus, the price sensitivity of the buyers and the government efficiency mandate act together to create a very large market at the 10 SEER efficiency level, with very few products sold at higher efficiencies as shown in Figure 5.2.

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[5] The seasonal energy efficiency ratio (SEER) is defined as the total cooling of an air conditioner in Btu's over its annual usage period, divided by the total electric energy in watt-hours consumed by the unit over that period. A higher SEER rating signifies a more efficient system. The efficiency of each air-conditioning model is certified by the Air-conditioning and Refrigeration Institute (ARI) which is a voluntary, non-profit organization comprised of manufacturers of air-conditioning, refrigeration, and heating products.

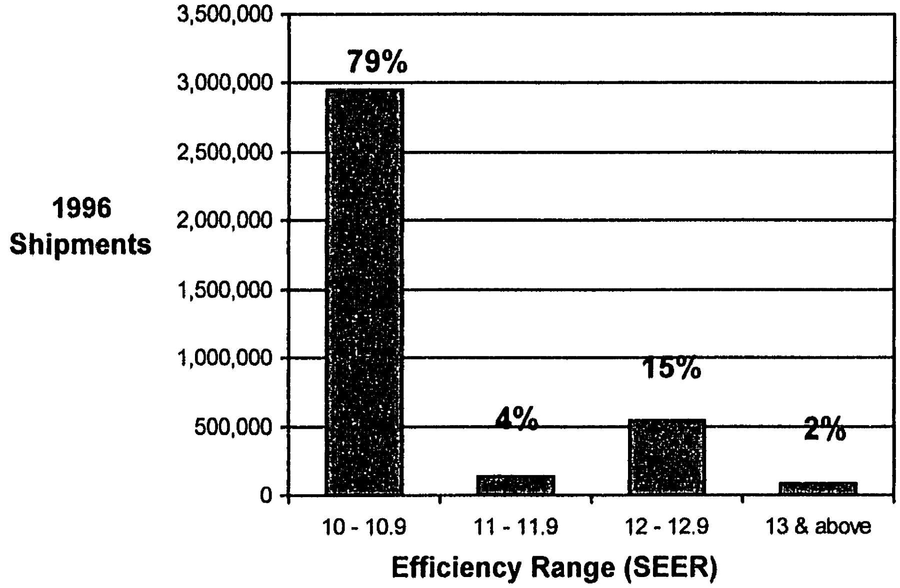

Figure 5.2 Government mandated efficiency and price sensitivity of the buyer creates the largest market at the 10 SEER efficiency level.[6]

The domination of the 10 SEER units can also be illustrated by considering the average efficiency of all units produced industry-wide, weighted by the unit sales volume. This figure has only showed a marginal increase since 1992 (Figure 5.3), further demonstrating that there has been little shift in the market away from these base efficiency units. Given the market domination of the 10 SEER units, we have chosen to focus on this efficiency category for the purpose of studying technology integration in residential central air conditioners.

[6] ARI Unitary Small Equipment Section's Quarterly Report of Domestic Shipments by Seasonal Energy Efficiency Ratios, ARI, Arlington VA, 1997. Data shown is for split system air conditioning condensing units.

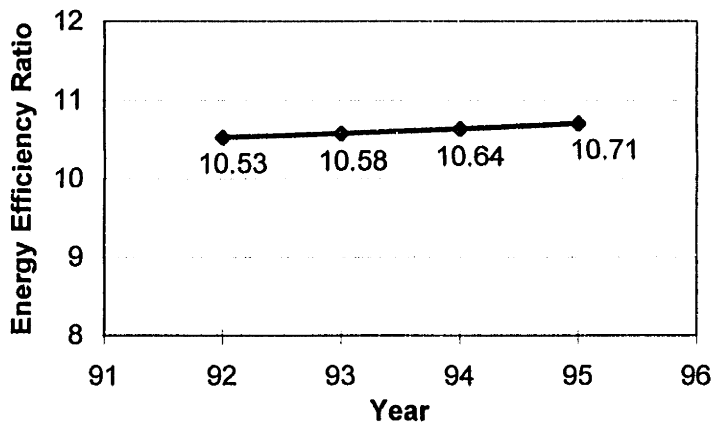

Figure 5.3 The shipment-weighted average of central air conditioners remains near 10 SEER, but has shown a slight increasing trend.[7]

Reliability is another basis for differentiation that is becoming increasingly difficult to achieve. A 1993 survey found Trane and Lennox leading the industry in the lowest repair rates, although by only a very small margin.[8] Differentiation based on reliability is difficult because the products from different manufacturers have the same architecture and often utilize components from the same suppliers, and thus have very similar inherent reliability. Differences in reliability are additionally difficult to achieve since most issues are related to the quality of the installation performed by the contractor and not the performance of the manufactured unit. The Consumer Reports survey found very similar reliability levels across all major manufacturers with the difference between the best and worst reliable brands being only four percentage points. Furthermore, central air conditioners overall are very reliable appliances with repair rates averaging well below 10%.

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[7] *1996 Statistical Profile of the Air-Conditioning, Refrigeration, and Heating Industry*, ARI, Arlington, VA, 1996

[8] Consumer Reports, June 1993

Operation:

The principle components of an air-conditioning system are show in Figure 5.4 which is designed to transfer heat from one airstream to another. Air is cooled as it flows over a heat exchanger where refrigerant, under pressure, is rapidly expanded to a lower pressure state. The act of expansion absorbs heat from the airstream through a heat exchanger called an evaporator. The evaporator is constructed from aluminum fins that have been attached to coils of copper tubing which carry the refrigerant. Following the expansion process, the refrigerant is drawn into a compressor which then raises the refrigerant pressure. The compression process significantly heats the refrigerant which is then cooled by passing the high pressure refrigerant through another heat exchanger, called a condenser. The construction of the condenser heat exchanger is very similar to the evaporator described above. The cooled, high pressure refrigerant leaves the condenser and then flows to the evaporator to begin the process over again.

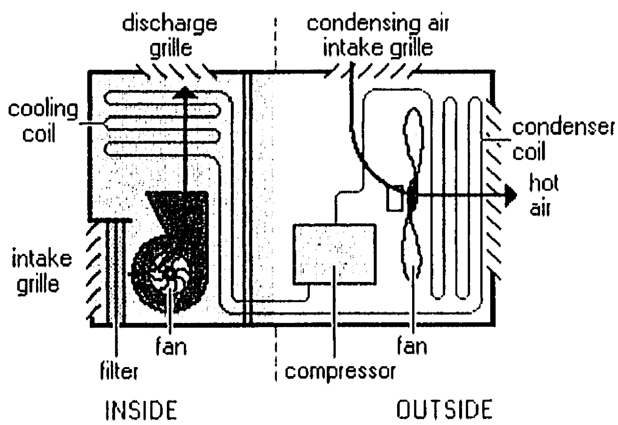

Figure 5.4 Principle components and operation of an air conditioner

Residential central air-conditioning systems are configured with the evaporator coil and fan located within the air ducts of a home while the compressor, condenser, and the condenser fan are located outside of the home. The condensing unit represents most of the purchase cost and complexity of the central air conditioning system. It is comprised of the compressor, heat exchanger, fan, fan motor, cabinet, refrigerant valves, and compressor electronics configured as a rectangular box measuring 2-3 ft on a side as shown in Figure 5.5. The technology integration for the condensing unit is the focus of this study. The words "air conditioner" in the following text generally mean the condensing unit.

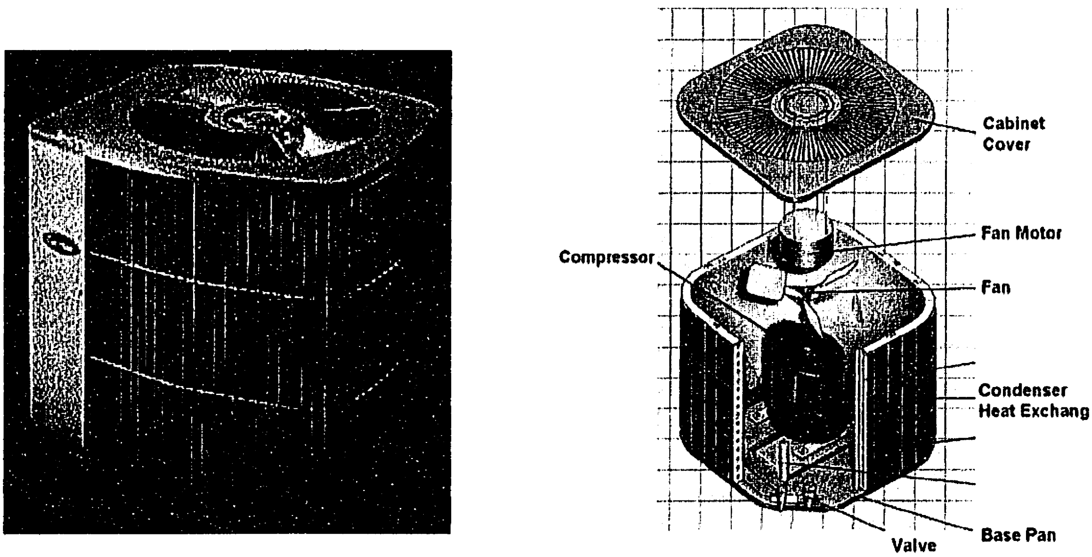

Figure 5.5 External view and internal schematic of a typical condensing unit showing the major components **(source: Carrier and Goodman product literature)**

Design:

The product design is accomplished through the selection and integration of the components of the condensing unit to achieve targets established for capacity,[9] energy efficiency and cost. For a typical manufacturer, from 75% - 90% of the material cost comes from purchased components which include the compressor, fan, fan motor, and electronics. The air conditioning manufacturer typically produces its own heat exchangers

[9] Capacity is the amount of heat the system can extract from an airstream over a specific period of time. Capacity is expressed as the number of Btu's of heat that can be extracted from the air in one hour (Btuh). Product sizing is typically expressed in tons of cooling capacity where 1 ton equals 12,000 Btuh. Residential Central air-conditioning units are typically offered in 1, 1.5, 2, 2.5, 3, 3.5, 4, and 5 ton sizes. A typical rule of thumb is to use 1-ton (12,000 Btuh) of capacity for every 500-1000 square feet of living space.

from copper tubing and aluminum, and then assembles all of the components into a cabinet which is fabricated from sheet steel. The principle tradeoff made by the designers is to match the compressor with the shape, size, and design of the heat exchanger to achieve the desired efficiency and capacity. Software tools assist the designer in making these tradeoffs.

Discussions with those knowledgeable about the design process commented that it is a fairly straightforward task to create the basic efficiency (10 SEER) units. The same components are available to and used by all of the air conditioner manufacturers. Computer design programs that enable the engineer to size and design the heat exchanger to match the compressor are also readily available. The higher efficiency units (14 -17 SEER) require significantly more engineering expertise to produce. Design tradeoffs become more subtle and difficult as one seeks to squeeze the maximum cooling capacity from every watt-hour of electricity consumed. Deeper knowledge regarding heat transfer and air flow is required to optimize the design of the heat exchangers which is not readily incorporated into the analytical design tools.

The government efficiency mandate, and the resulting domination of the 10 SEER unit in the market, presents an interesting technology integration issue for the product designer. Technological improvements in compressors have steadily reduced their cost and increased efficiencies. Directly substituting a new, more efficient compressor into an existing condensing unit design would raise the efficiency above 10 SEER. Since the target efficiency in this market is 10 SEER, the designer must de-rate, or otherwise modify the design of the other components to bring the efficiency back to the 10 SEER target. One approach is to modify the condenser heat exchanger to make it smaller and/or less efficient. A smaller heat exchanger means less material is required to produce it, and thus, the cost of the condensing unit is lowered.

Given that the architecture is fixed, and the targets for efficiency and capacity are also constrained, the process of technology integration is therefore to select components with specific characteristics and then integrate them together through a series of tradeoffs to produce the a design that meets the capacity and efficiency targets.

Technological Environment

As noted above, central air-conditioning is an example of a fairly stable technological environment. The principle components and the overall system architecture have changed little since the early 1900's. Technological changes have come in the form of improvements to components rather than the re-configuration of the air-conditioning system architecture. Some of these changes have been fairly significant such as the switch to non-CFC refrigerants, the introduction of scroll compressors,[10] and the utilization of internally-patterned-copper tubing.[11] These innovations clearly fall within Christensen's "sustaining" category since they all help to increase the performance of the product as evaluated by the value network of suppliers, manufacturers and users (Christensen 1997). Consistent with Christensen's conclusion concerning sustaining innovations, all manufacturers in the central air-conditioning market have been able to incorporate these technological advances into their products with little difficulty.

Technology Integration at Carrier and Goodman

The technology integration environment in the residential air conditioning market is primarily defined by the following factors:

- The product architecture is very stable
- Major component technologies are outsourced
- All industry players have equal access to component technologies and knowledge of competitor designs

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[10] Scroll compressors utilize orbiting, intertwined spiral scrolls to compress the refrigerant. These compressors are typically more efficient, more reliable, quieter and utilize fewer parts, than the traditional reciprocating compressor. Reciprocating compressors use an oscillating piston within a cylinder to compress the refrigerant.

[11] Internal grooving patterns on the refrigerant side of the copper tubing increase the turbulence of the refrigerant flow which enhances heat transfer efficiency.

- Integration complexity is fairly minimal at the 10 SEER level
- Technological advances are incremental, sustaining, and are readily adopted by all industry participants

The technology integration questions facing Carrier and Goodman for the current product generation are not whether a vapor compression cycle or a fin-tube heat exchanger design should be used. These questions about which technological possibilities to employ have been implicitly answered during the steady incremental evolution of this industry over the past several decades. Utterback's dominant design has emerged within Christensen's value network where suppliers, manufacturers, dealers, installers, homeowners, and federal regulators have come to expect a central air conditioning unit to contain certain components, to look and function a certain way, and to be optimized according to a well-understood set of performance criteria (Utterback 1994; Christensen 1997).

The technology integration questions that Carrier and Goodman must answer concern how to design and manufacture the air conditioners within the predefined product architecture and to the market's cost/performance requirements. Which suppliers of components should be used? How many different product variations should be produced? How much commonality should there be across the product line? These are but some of the questions that Carrier and Goodman answer as they make tradeoffs between technical possibilities provided by the components and the business opportunities of the market.

Business Strategy

Carrier

The "invention" or more accurately, the first practical use of vapor compression refrigeration is attributed to Willis Carrier, who in 1902, designed an air conditioning system for a New York printing company to resolve quality problems arising from temperature and humidity fluctuations. Willis Carrier formed the Carrier Engineering Company in 1915 which grew into the $6 billion enterprise that today is a unit of United

Technologies Corporation.[12] Carrier offers a full line of heating and cooling products for both residential and commercial markets, ranging from small window room air conditioners, to massive chillers capable of cooling and heating shopping malls, airports and large office buildings.

Carrier prides itself on its superior engineering capability that began with Willis Carrier and continues today as one of the hallmarks of its strategy. Carrier maintains a central technology development function separate from its business unit engineering functions and funds cooperative programs at UTC's corporate research and development center. As one Carrier manager remarked, this strong engineering competency causes Carrier's culture to be "very engineering driven". The engineering focus and excellence is also visible in the special projects Carrier has accomplished which include a very unique environmental control system for the Sistine Chapel and the preservation of a 500 year old frozen Incan human sacrifice for the National Geographic Society. The Carrier brand name is widely recognized throughout the world as symbolizing excellence in residential and commercial HVAC engineering.

Carrier's strategy in residential central air conditioning is to maintain the image of a market leader through superior engineering and technology and through multiple brands that target the entire market in segments ranging from the low to the high end. A director within the residential business noted, "we pride ourselves in being the technology leader in HVAC".[13] In an attempt to moderate this technology-driven strategy recently, Carrier's vice president and general manager of the Residential Products Group remarked that Carrier has sought to shift the source of change in its products from being technology driven to being more market driven (Miller 1997). This shift is taking form in their "consumer-brand-marketing-strategy", where Carrier uses its sub-brands to address specific markets which differently weigh the factors of price, dealer competency, and efficiency in making buying decisions. The products in each of these brands will be

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[12] Carrier was acquired by United Technologies in 1980

[13] Carrier Excels Year After Year, Professional Builder, 61:96, September, 1996

specifically engineered and tailored to the preference weighting of the target consumer segment. Carrier's objective is to give the consumer a compelling reason other than price to choose one of its products (Miller 1997).

Goodman Manufacturing Company

Goodman Manufacturing is a privately held company that was founded in 1975 by Harold Goodman in Texas to produce flexible ducts, cooling coils, and plastic registers. Goodman entered the HVAC equipment business in 1982 with the purchase of the Janitrol air conditioning product line from Tappan. Annual sales were estimated to be approximately $600M in 1994. Goodman has been steadily expanding the Janitrol product line to where it now includes residential heating and cooling products, including window room air conditioners, central air conditioners, gas and electric furnaces, and mini-split systems.

Goodman's clear strategy is to be the price leader in the industry. Their goal is to provide equal performance for significantly lower cost - typically at least 20% lower. They achieve this strategy by being a fast follower of the designs from technology-lead manufacturers such as Carrier. Several Carrier personnel commented that Goodman "just copies our designs." Goodman spends little effort on engineering its own designs and has a very limited technical staff which was referred to as a "virtual skeleton crew of engineers" by one visitor (Wheeler 1992). Further comments by dealers and service people confirm that Goodman clearly copies at least the component decisions of other players in the market. Their strategy is to gain a cost advantage through technology integration, product design and manufacturing strategies, and not through the use of low cost, low quality components (Schulz 1992).

Technology Integration Strategy

Carrier

Carrier's technology-driven business strategy, and comprehensive product lines focused on specific market segments, leads to a fairly complex technology integration approach. The Carrier brand[14] alone has twenty-three different models over the seven sizes in the 1.5- to 5-ton capacity range. The number of models in this brand grows to fifty-seven when all units above 10 SEER are included in the count. Multiple models for each capacity size at the same efficiency result from designs for different voltage configurations (four 10-SEER models are each offered with three different voltage configurations). This leads to the use of different fan motors and compressors specifically selected for these voltage configurations. Carrier also seeks to ensure its supply of compressors at competitive prices by using multiple sources for each of the compressors used in the twenty-three models. This leads to further growth of the product line when the additional internal model designations are considered for each compressor brand used in a single condensing unit model.

Each model variant presents Carrier with a technology integration challenge that is different since each model uses a different set of components. Carrier addresses the technology integration requirement by individually optimizing each design around its specific set of components. For example, if one compressor type/brand is slightly more efficient, the designer will tradeoff or reduce the size of the heat exchanger coil to maintain the 10 SEER target. The driver for this approach is very clear - Carrier wants to minimize the unit material cost of each product design as much as possible. The greater performance of a compressor can be used to remove material from the heat exchanger. A smaller coil is inherently cheaper because it uses less metal and also because a smaller coil enables a smaller steel cabinet to be used which further reduces costs.. The capability to

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[14] Carrier also produces the Bryant, Day & Night, and Payne brands

optimize each specific product model design is enabled by the deep engineering competency embodied in the knowledge and practice of the product engineering staff.

The ability to wring as much material out of the unit for a given capacity and efficiency is an indication of technology integration performance which can be measured through the proxy of weight. Since most of the elements of a condensing unit are metal, a better integrated design will use less metal, and hence weigh less. Carrier has demonstrated leadership in this measure of performance, consistently providing the lowest weight units over much of the product line. An example is shown in Figure 5.6 for a 2.5-ton condensing unit in 1996.

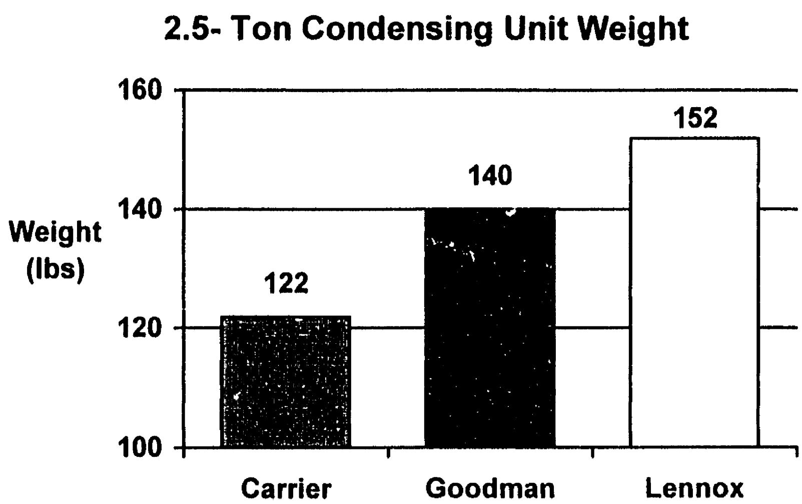

Figure 5.6 Carrier has been a market leader in technology integration as measured by weight of the condensing unit.

Carrier's model-specific technology integration strategy can be seen in the variety of product attributes measured over the models comprising the product line. The number of variants shown in Table 5.1 reflects Carrier's goal to design products for specific market segments, to utilize multiple component sources, and to reduce the unit material cost to be as low as possible. The net result of this strategy is a more complex product line that leads to greater complexity in design, testing/qualification, manufacturing, and distribution. This complexity adds costs and difficulty in maintaining quality and smooth value chain operation. Carrier expects to recover these additional costs through greater sales and higher margins enabled by their market segment focus. The complexity notwithstanding, this technology integration approach is clearly consistent with Carrier's engineering-driven strategy to lower the individual material cost of each design while providing a complete line of products for several different market segments. While cost is important in this price-sensitive low-end product line, Carrier is seeking to cause the buying decision to be made on a basis other than price.

Table 5.1 Product attribute comparison for Carrier and Goodman 1.5 to 5 ton condensing units

Product Attribute	Carrier	Goodman
Footprint platform	3	2
Height	6	5
Fan Diameters	3	2
Compressor Brands	4	2
Fan Speeds	5	1
Motor Models	12	2
Model Variants	23	11
Price	-	20+% lower

source: Goodman and Carrier product information and dealer supplied information

Goodman

Goodman's price-leadership business strategy is synergistically coupled to a very different technology integration strategy compared to Carrier. Goodman's product line over the 1.5 to 5 ton capacity range contains eleven different models. Two models are offered with two different voltage configurations and one model is offered with three voltage configurations for a total of seven model/voltage configurations. Carrier offers twelve model/voltage combinations with four models each having three different voltage configurations. Goodman does not seek to markedly segment its customers and primarily focuses on the basic efficiency units for the price-driven buyer. They have recently introduced a line of slightly higher efficiency 12 SEER units, but have nothing to compete with Carrier's high efficiency 14-17 SEER products. President Harold Goodman commented on their strategy as being "…..high quality but simple, and with a good price" (Miller 1994).

The published product data strongly suggest that Goodman is following a product platform approach for its technology integration strategy. Recalling the discussion in Chapter 4, a platform approach strives to minimize product complexity by using common components along with a platform architecture that enables model variants to be introduced very quickly and efficiently. The supporting evidence that Goodman is following a platform approach comes from the model attributes shown in Table 5.1 . Goodman has a physical product platform - the base pan of the unit (refer to Figure 5.5) which is a constant size across all models in the 1-4 ton capacity range. The common base platform enables Goodman to use the same shape of heat exchanger and the same top cover of the cabinet across all models. The height of the Goodman unit, determined by the height of the heat exchanger, is scaled upward for each capacity model. Carrier, in contrast, utilizes three different base pan sizes with a correspondingly different heat exchanger shape designed for each base pan.

The product data also show a marked reduction in component variety for Goodman compared to Carrier as shown by the comparison in Figure 5.7 Fewer compressor brands, motor types, and fan designs are used. As demonstrated by Black & Decker, following a platform strategy can lead to considerable economy since fewer product designs and components need to be managed, qualified, and maintained. Fewer component brands lower costs by enabling greater economies in sourcing. The design effort for a less complex product line where each model is similar in shape and component content is more efficient and is commensurate with Goodman's lean engineering and technical resources. The manufacturing process is similarly less complex and more efficient with a greater commonality of components. The lower design and manufacturing complexity derived from the platform approach reduces the engineering effort Goodman must apply to integrate their designs. Goodman appears to have a substantial cost margin that they can trade off against the engineering effort required to produce a highly integrated design whose purpose is to remove as much material as possible from the product. Goodman can offer a product of equal capacity and efficiency at a price point at least 20% lower than Carrier while using more material to produce it (resulting in the higher product weight shown in Figure 5.6).[15]

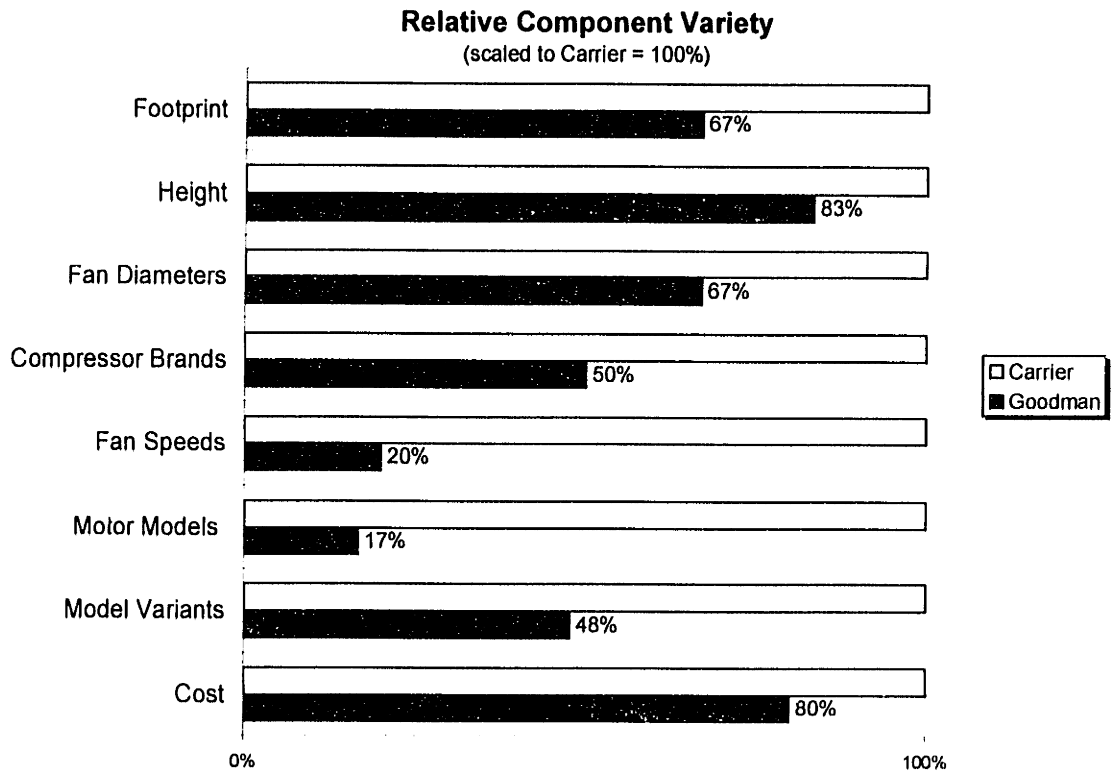

Figure 5.7 Goodman utilizes less component variety and more design commonality compared to Carrier

Full Product Line Complexity

The data presented above, which focus on one brand and one product line, do not reflect the degree of product complexity Goodman and Carrier use to address the entire central air conditioning market. The magnitude of this greater complexity can be seen when all brands, models, capacities, efficiencies, and voltage configurations are considered. These data, shown in Table 5.2, were derived from the published results of the Air Conditioning

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[15] Goodman's cost advantage is further augmented by the limited expenditures on developing,

& Refrigeration Institute's performance rating program[16] and show that Carrier manages over four times more model numbers than Goodman.

Table 5.2 Number of unique model numbers for residential central air conditioning units across all Carrier and Goodman brands, trade names, and efficiencies.[17]

Company	Brands	Trade Names	Model Numbers*
Carrier	4	26	178
Goodman	7	7	43

*does not contain duplicate model numbers listed across different trade names and brands

Not only is there additional cost to design each of the many different models with its unique combination of components, but every model must be life-tested and qualified to meet ARI certification. Further, there are the additional costs from the increased inventory complexity and the logistics of maintaining a larger number of product models.

Reliability

Reliability deserves particular attention since a low cost air conditioner of equal cooling capacity and efficiency that is unreliable and needs significant maintenance cannot be judged to be a competitive product. The quality of Goodman's products is of considerable debate in the HVAC industry. Neither Carrier nor Goodman release warranty claim and/or repair data so a quantitative answer is hard to achieve. A Consumer Reports study did not find enough installed Goodman units in 1992-1993 to be included in its reliability survey, though it did find only marginal differences among those manufacturers listed, including Carrier.[18] Carrier personnel have suggested that they consider Goodman products to be of clearly inferior quality.

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maintaining and supporting their dealer channels.

[16] Directory of Certified Unitary Equipment Standards 210/240 270, August 1, 1996 - January 31, 1997, Air Conditioning and Refrigeration Institute, Arlington, VA.

[17] NAECA products only

[18] Consumer Reports, June 1993

Although I could not establish a qualitative answer to this debate, I was able to gain considerable insight into the issue by following an extensive internet discussion on this question and through follow-up discussions with contractors and dealers who were familiar with both Carrier and Goodman units[19]. Extreme comments on good and bad views of Goodman central air conditioner quality are frequently expressed. The news group discussion was nearly equally divided among favorable and unfavorable comments about Goodman products.

Follow-up discussions with contractors and dealers enabled several themes to emerge which I believe explain the disparate views on Goodman's quality and reliability. The competency of the dealer and the quality of the installation job is the single greatest factor affecting the reliability of the unit. The inherent quality of the Goodman units appears to have improved significantly over the past few years to a point where it arguably matches that of Carrier and other long-established manufacturers - provided that the installation is done correctly. Dealers cite Goodman's use of industry standard quality components as the reason for the parity in reliability. One key difference between Carrier and Goodman, however, is in the selection of the dealer or distributor. Carrier is very careful in selecting its dealers so that they have the competency, skill and knowledge to accomplish correct HVAC system design and installation. Managing and supporting this higher quality distribution channel is a major contributor to Carrier's higher unit price. Goodman in its pursuit of a low cost strategy, spends significantly less (if any) effort on qualifying its dealers to ensure they have the appropriate skills to accomplish a quality installation, and thus, there are more faulty installations. The historical perception of lower Goodman quality appears to be related as much to dealer incompetence as it is linked to measurable attributes of product quality. One dealer remarked that Goodman could resolve the quality debate in its favor if it would be more selective in its dealer affiliations.

[19] This discussion was initiated in the alt.hvac newsgroup by a question posted from a person who was considering the purchase of a Goodman central air conditioner and he wanted to know what the opinions were of contractors and dealers as to the quality, reliability and performance of these units.

Comparison and Implication of Technology Integration Approaches for Carrier and Goodman

At the outset of this chapter, we suggested that the residential central air conditioner industry presented an environment where the stability in both the market needs and the technological possibilities would serve to highlight the strategic nature of technology integration and the importance of a synergy and coherency with the firm business strategy. The study of Carrier and Goodman, who each follow very different technology integration approaches and different business strategies, illustrates how technology integration influences business strategy and how business strategy is part of the technology integration process.

Carrier is using its dominant engineering expertise and culture, along with a market-segment-focused brand and product strategy to shift the purchase decision away from price alone. Through a series of targeted products, Carrier expects the additional sales from the segmented markets to offset the costs associated with a significantly more complex and a more highly-engineered product line and the considerable expense of maintaining and supporting their distribution channels. Their product-specific technology integration approach is both an enabler and a result of this business strategy. In contrast, Goodman is pursuing a low-price strategy with a comparatively more limited product line to reach buyers whose principle purchase motivation is price. The maturity of the product design, along with the low technological and market uncertainty, makes Goodman's platform approach to technology integration highly successful and synergistic with its business strategy. The platform leads to commonality of designs, components, and manufacturing processes across the product line to achieve economies of scale which support their low price-leadership business strategy.

The government-mandated efficiency "floor" of 10-SEER is likely to remain the competitive battleground in this market for some time. This is primarily attributable to buyer focus on low initial cost rather than considering the more favorable life-cycle cost of a higher priced, but more efficient unit. Almost every dealer that I communicated with lamented that "....unfortunately, most US buyers are more concerned about price than anything else including efficiency and quality". A second factor reinforcing the competitive focus on the low-end of the market is the nature of most technological advances. Illustrated in Figure 5.8, most technological advances in manufacturing processes, heat exchanger design, and compressor performance can be applied equally well to all efficiency models of air conditioners. Thus, although these technology advances can be used to lower the cost of higher efficiency units, making them more attractive to buyers, these same advances can also be applied to the lowest efficiency models (moving from P_1 to P_2) since there is a common product architecture across all models. Thus, a price-leader competitor, such as Goodman, can further lower the cost of the 10-SEER units which keeps feeding the desires of most buyers seeking lowest up-front costs. The net result is that most technology advances will continue to keep the majority of this market in the highly price-competitive low-end 10-SEER range.

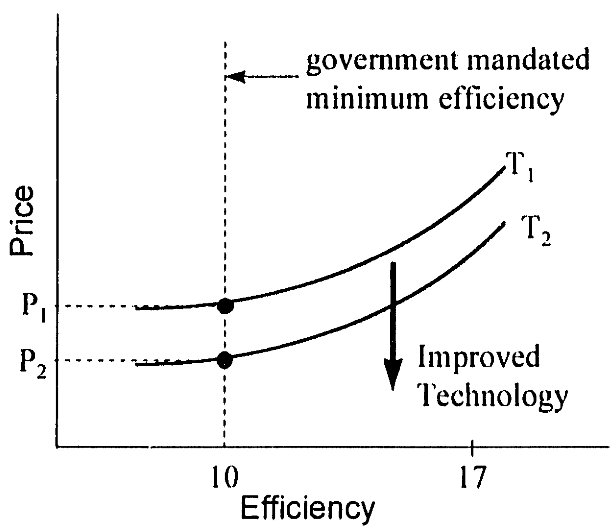

Figure 5.8 Technological advances that are applicable to all efficiency ranges, intensify price competition and maintain the focus on the low efficiency units.

A technological advance, such as that illustrated in Figure 5.9, which lowers the cost of higher efficiency units to a greater extent than low efficiency models could provide a mechanism for the market to significantly shift to higher efficiency units. It is difficult to envision a new technology, consistent with the existing product architecture, that would enable this to happen. However, a new product architecture, using different component technologies, may have future potential to reduce the cost of higher efficiency units sufficiently to shift the market from the current architecture and 10-SEER efficiency level.

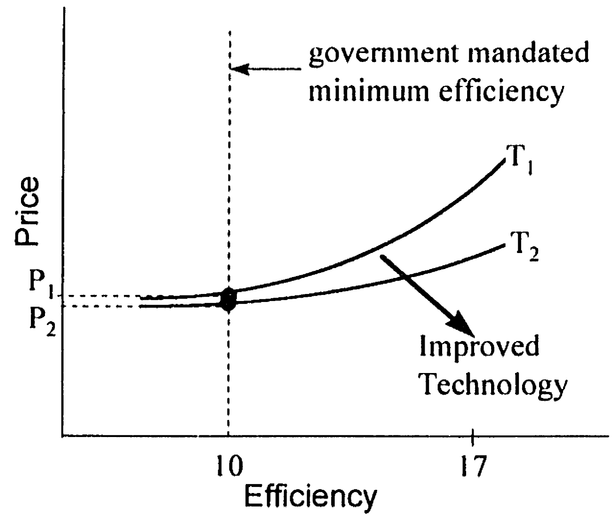

Figure 5.9 Technological advances that preferentially lower the cost of higher efficiency units can shift the market away from the lowest efficiency units.

Implications

Both Carrier and Goodman have been relatively successful to date in their pursuit of different business and technology integration strategies as measured by market share. Figure 5.10 shows that Goodman has been increasing its market share significantly since 1991, but not at the expense of Carrier's fairly constant market-leading share of about 20%. Predictions about future success for these two companies are difficult since the residential central air conditioning product lines are just one element of a much broader HVAC business pursed by Carrier and Goodman. Synergy and leveraging with other elements of the business can be missed when focusing on a single product line or business segment.

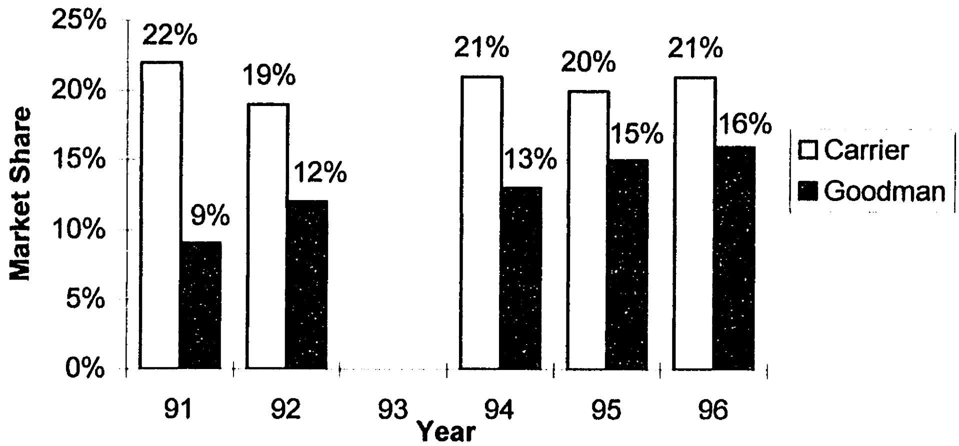

Figure 5.10 Goodman is growing market share compared to Carrier's stable share
(source: Appliance Manufacturer)

If the market stays extremely price competitive and concentrated at the low end of the efficiency range, there are several indications that Goodman's synergy between its technology integration and business strategies is potentially more effective than the synergy between Carrier's business and technology integration strategies. Carrier's superior engineering expertise is likely to lead to greater comparative success for technological advances that require new product architectures that can preferentially reduce the cost of higher efficiency units as previously shown in Figure 5.9. However, in the absence of such a technological change, Carrier should focus on several factors concerning Goodman's strategy that may be worthy of an adjustment in their strategic approach:

1. *Goodman has been more efficient in capturing market share*
2. *Carrier's product complexity supports Goodman's Strategy*
3. *Goodman's platform strategy and demonstrated learning at the low-end of the market can be leveraged to move up-market*

Goodman has been more efficient in capturing market share

The platform strategy for technology integration that Goodman is pursuing has clearly been successful in moving past other manufacturers to achieve the second highest market share for residential central air conditioners. Leveraging the product platform design and commonality of components, Goodman has achieved equal performance, arguably similar reliability, and price points at least 20% lower than Carrier. The cost-conscious homeowner and home builder markets have responded by growing Goodman's market share significantly since 1991. The effectiveness of its business and technology integration strategies appear to be considerably more efficient than Carrier given that Carrier enjoys a four point lead in market share but at the expense of a four-fold increase in product line size and complexity (see Table 5.2).

Carrier's product complexity supports Goodman's Strategy

As a fast follower, Goodman enjoys the benefits of Carrier's lead in employing new component technologies since the product architecture is highly modular and easy to reverse-engineer. Goodman can wait for Carrier to work out the engineering design problems and to utilize new components before imitating the same design and sourcing the same components. Carrier's greater number of product models and strategy to have multiple component sources further aids the entire industry by qualifying a larger number of components that its competitors can select from to create their own products. This is a substantial benefit to Goodman by providing it with a wider range of component possibilities.

Goodman's platform strategy and learning at the low-end of the market can be leveraged to move up-market to challenge Carrier in the higher performance product categories.

Meyer and Lehnerd have shown how a platform approach creates economies of production and efficient means to develop derivative products that enable firms to use the low-end part of the product line as a beachhead to make an up-market assault on the higher performance, higher margin end of the product spectrum (Meyer and Lehnerd 1997). Christensen notes numerous examples where established market leaders have abandoned the low end of their product line in the face of new low-cost competitors to focus their efforts on higher-end products (Christensen and Rosenbloom 1995). Unfortunately, the retreat of the established firm usually continues until it finds itself no longer the dominant player in the industry, but rather a niche player holding on to a very small high-end segment.

There are some signals that this process of moving using low-end learning combined with a platform strategy to move up-market is having some success. Goodman has been steadily expanding their product line by including higher efficiency units and new products such as mini-split systems. Goodman is also seeking to move beyond domestic markets and expand its business in the Pacific Rim (Miller 1994).

Evidence suggests that Goodman is learning and gaining in its technical competency. Although absolute reliability numbers are highly debated, all of the industry experts consulted in this study agreed that Goodman has been significantly improving their product quality. The technical learning can also be seen in the weight of the units which we discussed earlier as being a proxy for measuring how well the components of the air conditioner are integrated together. Goodman has closed the gap in weight considerably since 1991 across the 1 - 5 ton product line. An example is illustrated in Figure 5.11 which shows the comparative weights of a 3-ton condensing unit.

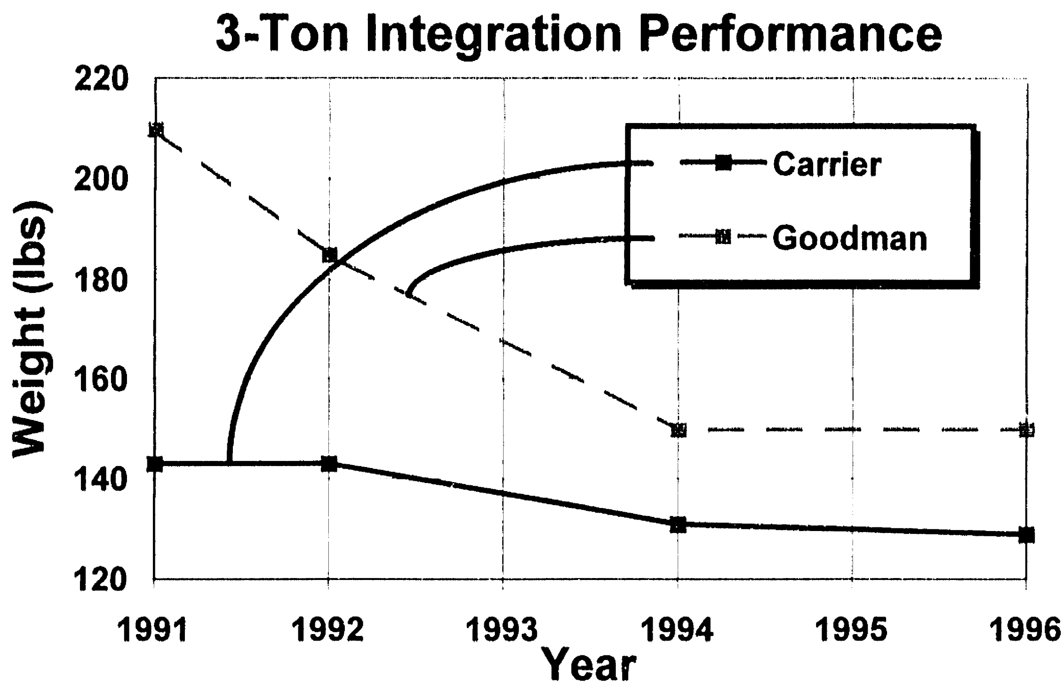

Figure 5.11 Goodman has considerably improved its technology integration capability as measured by the weight of the condensing unit.

Goodman also faces challenges to continued growth in its market share. Clearly, it must resolve the quality debate in its favor through increased attention to its dealer channels. It will be particularly challenged to achieve this without adding costs which disrupt its ability to be the low price industry leader. Goodman's lean technical staff is particularly suited to being a follower in a stable product architecture for the price sensitive 10-SEER market. A disruptive technology that requires strong technical competencies to implement could pose considerable trouble for Goodman.

Assuming that the market and technology environment remains stable for the near future, the most successful approach might be a hybrid of Carrier and Goodman strategies. Carrier has demonstrated the importance of managing its distribution channels to achieving a solid reputation for product quality and dealer service and Goodman has shown that a platform strategy can enable significant economies in engineering design and production. Combining Carrier's marketing and distribution strategy with Goodman's platform strategy may be quite successful in the market for low-cost, base-efficiency central air conditioners

Chapter 6 - Conclusions

This study has presented a way of thinking about technology integration that provides some practical insight for management as well as the basis for future study into this competency. The business environment in many industries is increasingly relying on an ever-widening set of disparate technologies that must be linked together to form products, and thus, the importance of technology integration is arguably growing. Technology integration as a specific competency has only recently been addressed as an area of academic study. Much of the understanding of technology integration is embedded within the discipline of product development which seeks to answer much broader questions.

The definition of technology integration as being *the process of selection and combination of technological possibilities into a product or service that is successful in the marketplace*, suggests that this competency includes activities which range from very strategic to very tactical. Only viewing technology integration as the ability to generate the greatest technical performance from a given set of components misses the important fact that the technical performance may not be aligned with the desires of users and/or not compatible with the firm's competitive position within the industry. Similarly, a superior selection of technologies for a product from a competitive and market perspective can be lost to a lengthy and inefficient development effort that results in a missed window of opportunity or a product that misses its cost target. Therefore, we considered technology integration from the perspectives of both strategy and operational effectiveness.

Technology Integration from a Strategic Perspective

From a strategic perspective, technology integration must be coherent and synergistic with the business strategy of a firm. The set of viable technological opportunities can both drive business strategy and be driven by business strategy. The greatest success is achieved when both occur simultaneously in a synergistic manner. The coherency of the business and technical strategies must be maintained at all levels within a company ranging from the strategic mission of a firm all the way down to the tactical decisions of what specific components to purchase and from which supplier. Maintaining this consistency throughout the strategic hierarchy enables all participants to understand how to make the critical technical and business tradeoffs required to realize a successful product in a timely manner.

The case study on residential central air conditioners illustrated the linkage between the business strategy of a firm and its approach to technology integration. Goodman Manufacturing Company is pursuing a business strategy of having the lowest prices in the industry while being a fast follower to industry leaders such as Carrier. Goodman achieves its low prices through efficient manufacturing, a small engineering staff, a product platform strategy, and minimal distribution channel support. The platform strategy for technology integration used by Goodman is both an enabler and a result of their low-price business strategy. The product platform significantly reduces the number of different components, model numbers, and engineering effort required to service this market. All of the technology decisions from the product architecture down to the selection of component suppliers are coherent with the low-price strategy. Goodman has successfully exploited this strategy to grow its market share from 9% to 16% since 1991 to become the second largest manufacturer of residential central air conditioners in the United States.

Carrier has also been very successful in this industry by following an equally coherent, but quite different, set of technology integration and business strategies. Carrier's goal is to shift the purchase decision away from price and to focus on the value created by combination of quality, reliability, dealer competence, and price. Over 170 different models of condensing units are produced to create products targeted to specific market segments. Each model design is optimized around a set of components which vary significantly over the product line. This greater complexity of Carrier's product line and technology integration effort is coherent with their long tradition of engineering and technical excellence and is consistent with their value-driven business strategy. Carrier products carry a price premium over Goodman units due to the increased cost of developing, testing, and managing a significantly more complex product line as well as the greater cost for the significant effort Carrier spends on developing and maintaining its distribution channel. Given that Goodman is a privately held firm, and that Carrier is a subsidiary of United Technologies, it was not possible to verify the comparative financial performance of these two companies in this market.

Although the case study revealed that both Carrier and Goodman have been successful to date, the future is not certain. Given market and technology dynamics that keep the bulk of unit purchases at the low-cost, 10-SEER level, price will remain a significant purchase driver. In the near future, a hybrid of the Carrier and Goodman strategies may be most successful. Carrier has demonstrated the importance of managing its distribution channels to achieving a solid reputation for product quality and dealer service and Goodman has shown that a platform strategy can enable significant economies in engineering design and production. Combining Carrier's marketing and distribution strategy with Goodman's platform strategy may be quite successful in the market for low-cost base-efficiency central air conditioners

This study identified the need for coherency between the business and technology integration strategies and presented an example of how two companies in the same industry have been successful to date pursing very different approaches. Much effort remains, however, to understand how to achieve and measure this alignment.

Technology Integration from an Operational Effectiveness Perspective

Technology integration was explored from an operational perspective to identify factors which enable the effective combination of technologies and components together to form the product system. The goal was to identify the principle factors that affect the process of technology integration and then to classify them according to the ability of management to control them. A combination of a review of the research into product development, and interviews with experts in systems integration pointed to several broad categories of factors which promote superior technology integration. Decisions and organizational structures that 1) promote business and technical linkages, 2) prevent biases, and 3) promote product design iteration are suggested as factors which are under the control of management and which significantly contribute to greater technology integration performance. Factors which increase the difficulty of technology integration that are typically beyond the control of management are technology and market uncertainty, the complexity of interaction between the components in the product system, and the degree of disruption that a prospective technology has on the existing value framework of the firm.

Remaining Issues

The results of this study pose a number of significant questions that need to be answered before a comprehensive picture of technology integration can emerge. The importance of coherency between the technology integration and business strategies was demonstrated, but, how is this alignment achieved? What metrics can we use to measure the degree of coherency and the viability of the strategies? Furthermore, it is clear from the literature and from interviews with systems integration experts, that making the choices from available technological possibilities is a major success factor, especially in environments with great market and/or technological uncertainty. Yet, we don't understand exactly how to make those decisions in a manner which blends the technical and business opportunities. The current level of understanding suggests that this ability stems from the wisdom and insight of seasoned managers that have broad technical and business understanding. More in-depth study into this 'wisdom" is needed to make this a useable management concept.

One particularly puzzling question that was posed at the beginning of this thesis was under what circumstances is it better for a firm to pursue a component-focused strategy versus a system-focused strategy. Stated another way, how much effort should be placed on knowing and improving the component technologies versus gaining advantage from superior system-level integration? The answer remains unclear, although results from this investigation suggest that the answer is likely connected with the environmental factors of market and technological uncertainty, product system complexity, and the degree of sustainability of the new technology combined with the business strategy opportunities available to the firm. Particularly interesting is the influence of the degree of interrelatedness and modularity of the component technologies to answering this strategic question. We speculate that they should be a significant determinant of which strategy to pursue, yet there is no well understood methodology for measuring modularity and interrelatedness.

The concept of improving the operational effectiveness of technology integration by promoting technical and business linkages, preventing technical biases, and promoting design iteration, deserves greater study to prove the completeness and validity of this idea. The product development literature and practitioners of system integration suggest that these three management-controllable behaviors are at least a solid beginning. The relative importance of these factors must also be better understood under the varying conditions defined by the three environmental factors of market and technological uncertainty, product system complexity, and the degree of sustainability of the new technology.

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