THE EVOLUTION OF SUPPLIER-CUSTOMER LINKAGES OVER THE PRODUCT LIFE CYCLE:

An Evaluation of the Automated Assembly Equipment Business in the Printed Circuit Board Industry

by

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ABSTRACT

The nature of the S-shaped product life cycle (PLC) curve has provided a popular framework for characterizing the underlying dynamics of many technical businesses. For innovative firms, understanding these life cycle dynamics is essential for successful implementation of technology and marketing strategy. However, another key aspect for such firms to consider is the kinds of linkages they build with their customer. Some firms work very closely with their customers in creating and distributing new products whereas others maintain a distance, and rely primarily on third party channels.

It is the contention of this thesis that for successful product development and distribution, firms need to be highly flexible in the kinds of supplier-user linkages that they form. These firms must recognize which region of the PLC curve that they are operating in and modify their relationships accordingly. It is my hypothesis that some firms are unsuccessful in capturing broad appeal for their products because they become stuck with extensive technical linkages (applications engineers, heavy technical interactions) with their traditional customers: The linkages prevent such firms from pursuing new technology and developing ties with other, perhaps more advanced customers.

This thesis examines suppliers of automated assembly equipment to printed circuit board manufacturers and investigates how these suppliers have adjusted to the industries' transition from through-hole to surface mount type board packaging schemes. In particular, the nature of supplier-customer linkages is evaluated, and several hypotheses are tested regarding how these linkages have helped or hindered assembly equipment suppliers' efforts to develop and market advanced assembly machines.

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BIOGRAPHICAL NOTE

Robert Crooker received his bachelors degree in Mechanical Engineering from Princeton University in 1983. At Princeton, he received the 'Dike Award for Excellence in Undergraduate Research.' After two years with Sikorsky Aircraft, Mr. Crooker joined Kollmorgen Corporation where he spent four years in product and process development for the discrete-wired circuit board industry. At the Massachusetts Institute of Technology Sloan School of Management Mr. Crooker has concentrated in both Technological Innovation and Marketing and has completed three Teaching Assistantships at the Sloan School. Mr. Crooker is especially interested in the development and marketing of new products and intends to specialize in the management of technology.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the participation of the four firms used in this study as well as several other companies which provided additional information. In addition, I am indebted to Brian Swiggett, of BPA, Inc. for suggesting that I use the automated assembly equipment industry for examining supplier-customer linkages.

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INTRODUCTION

Successful firms frequently form close ties with their customers as a way of gathering feedback on existing products as well as ideas for new developments. However, technology and markets change over time and so one might expect that these supplier-customer relationships must also change in some way. It is the contention of this thesis that the linkages supplier firms form with their customers must actually evolve with the product life cycle. For the purposes of this study "linkages" refer to direct personal contacts between supplier and customer firms in which information is readily exchanged.

Overview

In the marketing literature there has been considerable attention given to the 'voice of the customer' in product development. The conventional wisdom holds that the firms which are able first to identify customer needs and then to provide desired solutions are the most successful. In order to do this, supplier firms form many kinds of linkages with their customers, both in developing new products as well as in supporting existing ones.

Another key tenet of product development is the notion of the product life cycle curve. Most every product goes through such a cycle and it is one of the great challenges for today's firm to manage its development processes to keep pace with the natural birth, growth and decline of new product offerings. For this study, we define the product life cycle quite broadly as a **technology** life cycle and examine an evolution in printed circuit board packaging.

An area that has received relatively little attention, however, is the role manufacturer-customer linkages play over the course of the product life cycle. Manufacturers that

closely align themselves with key customers may benefit from their in-depth understanding of those customers needs, but in the long run may suffer if they are unable to develop new linkages as those customer's product needs evolve.

The Study

To explore this hypothesis, several firms in the printed circuit board assembly equipment business are examined. These firms supply capital process equipment which is used by circuit board assemblers in attaching integrated circuits, resistors and capacitors to printed circuit boards (PCB). In the past ten years, shrinking component sizes have changed the nature of PCB assembly: Traditional through-hole technology (THT) circuit boards are now being replaced by surface mount technology (SMT) type boards which is forcing the process equipment suppliers to develop significantly more complex equipment.

Specifically, through personal interviews, literature review, and company information, I examine manufacturer-customer linkages in order to determine how the assembly equipment suppliers (AES) have been able to track their customers' evolving needs from THT to SMT assembly equipment. From the evidence presented, it will be shown that indeed supplier-customer linkages play an important role in product development and in fact the broadly-defined product life cycle of the PCB is an important consideration for suppliers of this industry in managing their relationships with customers. I conclude with a list of several ways in which manufacturer-customer linkages must change over the course of the PLC.

Format of the Report

In Chapter 1, two important elements of product development, identifying the customer's need and the product life cycle are reviewed, followed by a discussion of how firms form communication linkages with their customers. Chapter 2 presents a brief explanation of PCB packaging technology and discusses the industry's transition from through-hole technology to surface mount. In Chapter 3, evidence from our study of AESs is presented in order to examine the theory presented in Chapter 1 within the

framework of an industry example. Chapter 4 presents the major findings of this study and Chapter 5 provides several additional findings that relate to other kinds of external linkages.

Chapter 1

PRODUCT DEVELOPMENT AND CUSTOMER LINKAGES

Voice of the Customer

Few would argue that new products can be developed in a vacuum without substantial input from potential customers. The users through their own experience are a rich source of new product needs. Generally, speaking, it has been shown that 60-80% of successful innovations come from the identification of a consumer's need.[1] The House of Quality approach to product development heavily relies upon gathering 'customer attributes' (in their words) and then linking this voice of the customer to engineering attributes.[2]

Borrowing from Eric Von Hippel's "Lead User" concept, certain advanced users of industrial products spawn key innovations in their fields which are later developed and marketed by other manufacturers.[3] Appropriate to this study, IBM, in an effort to solve its early PCB assembly problems developed one of the first automated component assembly machines, which was later 'handed off' to various equipment suppliers who then refined and improved upon this lead user concept.

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[1]John R. Hauser, "Consumer Research to Focus on R&D Projects," Journal of Product Innovation Management, (February 1984): 70.

[2]John R. Hauser and Don Clausing, "The House of Quality," Harvard Business Review, (May-June 1988): 64-68.

[3]Eric Von Hippel, "Successful Industrial Products From Customer Ideas," Journal of Marketing, (January 1978): 44.

Finally, the Japanese auto industry captured significant competitive advantage by making suppliers an integral part of the product development process. From these suppliers' perspectives, they are able to meet their customer's needs by collaborating on design projects using extensive linkages with both product and process engineers at the customers' plants. Indeed, suppliers enjoy space and facilities at some of their customer's factories to ensure good communication and problem solving effectiveness. This supplier-manufacturer partnership has resulted in significant lead time reductions as well as improved product fit with the customers' needs.[4]

The literature contains substantial additional support for this notion of designing around user's needs, but there are many pitfalls in putting theory into practice: How does one know which customer's needs to fulfill? How does a firm get close enough to the right customers to do this? Which technology is most appropriate to meet the broadest base of users' needs? How does a firm keep pace with changes in its core customers' requirements? Although answers to all of these questions is beyond the scope of this study, this last problem, keeping pace with evolving needs, is of particular interest for this thesis. Accordingly, a brief discussion of the product life cycle is in order to aid in understanding how customer's needs evolve over time.

[4]Kim B. Clark, "Project Scope and Product Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development," Management Science 35 (October 1989): 1260-1261.

Product Life Cycle

As articulated by Theodore Levitt in a 1965 HBR article, "the life story of most successful products is a history of their passing through certain recognizable stages."[5]

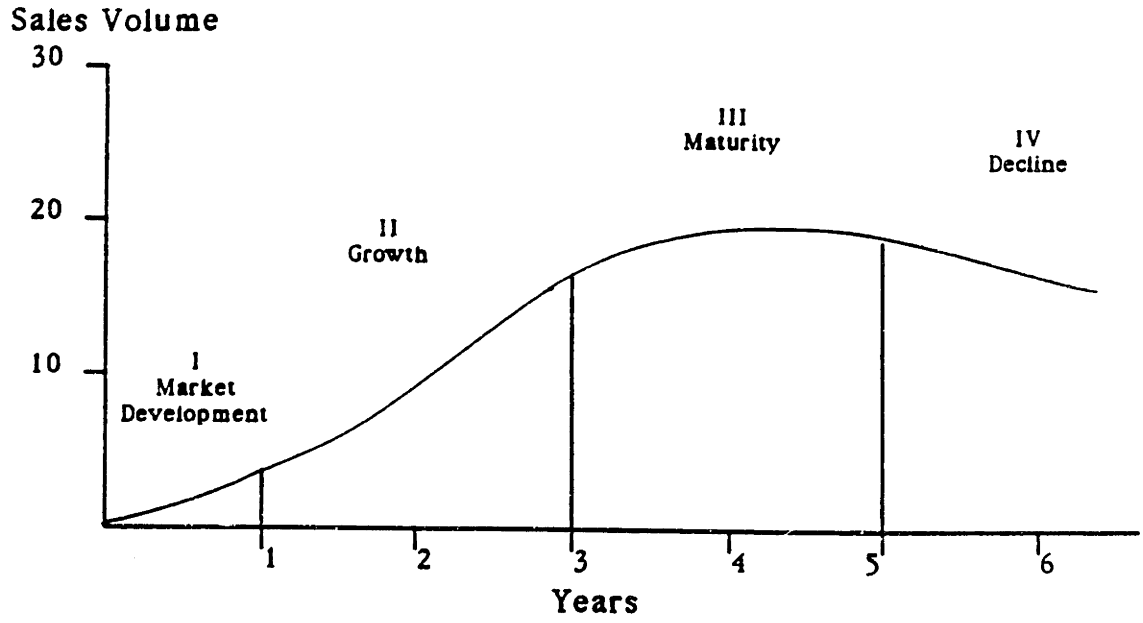

Figure 1: Stages of the Product Life Cycle

Each stage signifies substantial opportunity as well as risk for participating firms Businesses participating in emerging markets may enjoy significant advantage as the market grows, by establishing standards around their products and by dominating distribution channels. In the maturing phase, firms able to maintain a low cost position may prosper whereas others may be forced out of the market. Finally, through extensions of use or new applications the PLC may be regenerated, resulting in new growth and a delay in market maturity.[6]

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[5]Theodore Levitt, "Exploit the Product Life Cycle," Harvard Business Review, (November-December 1965): 82-83.

[6]Levitt, 88.

Although useful in theory, the PLC is somewhat difficult to apply as one is uncertain as to the duration of any particular life cycle stage, or when in time an inflection point will occur.[7] Nevertheless, the PLC has been put to many uses. Some advocate that a firm's market strategy must be related to the product stage in the life cycle.[8] Others claim that a company needs to gear its management style to stages of the PLC, saying that in the development stage, an entrepreneurial manager is required versus a more stable manager for the maturity phase.[9] In addition, most references to the PLC refer to successive generations of a product class such as the evolution of a tube style radio to a transistor radio to a Sony Walkman. For the purposes of this study, I define the product life cycle as **an evolution in the technology used to package electronic components.** This 'technology' life cycle then refers to the transition from through-hole type to surface mount style printed circuit boards. In this study, we propose that firms need to formulate their linkages with customers taking into account this 'technology' life cycle stage of their customers' products.

Customer Linkages

For this study, **customer linkages** denote the ways in which manufacturers form relationships with customers and defines how customers and manufacturers communicate with each other. For example, a supplier's design engineers may work directly with the customer's engineers in defining a new product or the supplier's sales force may develop relationships with top management at the customer to learn of future needs or key industry trends.

In particular, we focus our attention on manufacturers of capital equipment in which the customer is making a major investment (more than $50,000) in process equipment

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[7]R. N. Skinner, Launching New Products in Competitive Markets, (London: The Anchor Press Ltd., 1972), p. 20.

[8]Gordon F. Smith and Robert T. Davis, Marketing in Emerging Companies, (Reading, Massachusetts: Addison-Wesley, 1984), p. 85.

[9]Sak Onkvisit and John J. Shaw, Product Life Cycles and Product Management (Westport: Greenwood Press, Inc., 1989), p. 132.

used in the assembly of printed circuit boards. As such, equipment sales involve substantial technical discussions between the manufacturer and the customers, relatively high level final purchasing approval, and significant after-sale support activity.

Before exploring the linkages for this kind of business, it is worthwhile to review briefly some of the social science literature which contains many theories on organizational communication.

External Linkages

Schrader explores informal technology transfer through information exchange between different companies and illustrates not only how such communication occurs, but also how the linkage leads to economic benefit to both parties.[10]

Jackson studies the relationships between industrial firms and individual customer firms in the marketing context and explores the dynamics of customer relationships over time.[11]

Internal Linkages

Zirgen and Maidique stress the importance of interfaces between functional groups, the notion of organizational barriers to communication, and especially the threat of new technologies on markets in which established organizational communication and coordination networks exist.[12] Furthermore, several researchers have focused on the R&D - Marketing interface in various firms. Through a systematic study of 289 new product development projects, Souder classified a range of R&D - Marketing interface states from "harmony" to "disharmony" as a way of characterizing interactions between

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[10]Stephan Schrader, "Informal Alliances: Information Trading Between Firms," MIT Working Paper #38-91, March 1991.

[11]Barbara Bund Jackson, Winning and Keeping Industrial Customers, (Lexington: D.C. Heath & Co., 1985), pp. 1-10.

[12]Billie Jo Zirgen and Modesto A. Maidique, "A Model of New Product Development: An Empirical Test," Management Science 36 (July 1990): 870-874.

these two functional groups.[13] Tushman has explored communication networks in R&D labs and has developed a contingency model which characterizes three levels of linkages including within-project communication, within-firm interdependence, and finally linkages to external sources of information.[14] Gupta presents a detailed framework for studying R&D - Marketing integration and describes how organizational structure can facilitate or hinder smooth interaction between these groups.[15] In a more general study, Ruekert and Walker explore marketing's interaction with other functional groups, using a social systems and resource dependence model.[16] I will examine a portion of this model in more detail in our consideration of manufacturer-customer linkages in the AES industry.

System-Structural Model

The system-structural perspective, a theory which is widespread in the organizational literature maintains that one may view a social system by examining its environment, the organizational structure and processes and its outcomes.[17] Although Ruekert uses this model as a framework for studying marketing's interaction with other units in the firm, the perspective also is an attractive construct for studying manufacturer-customer linkages in the capital equipment industry.

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[13]William E. Scuder, "Managing Relations Between R&D and Marketing in New Product Development Projects," Journal of Product Innovation Management 5 (May 1988): 6-9.

[14]Michael L. Tushman, "Managing Communication Networks in R&D Laboratories," Sloan Management Review (Winter 1979): 37-40.

[15]Ashok K. Gupta and David Wilemon, "A Model for Studying the R&D - Marketing Interface in the Product Innovation Process," Journal of Marketing 50 (April 1986): 8-12.

[16]Robert W. Ruekert and Orville C. Walker, "Marketing's Interaction with Other Functional Units: A Conceptual Framework and Empirical Evidence," Journal of Marketing 51 (January 1987): 2.

[17]Andrew H. Van de Ven, "On the Nature, Formation, and Maintenance of Relations Among Organizations," Academy of Management Reveiw (October 4, 1976): 24-30.

One particular aspect of the theory that fits quite well with the manufacturing - customer linkage is the structural and process dimension. Ruekert outlines three facets of this dimension:[18]

Transactions
Communication Flows
Coordinating Mechanisms

In the assembly equipment industry studied, the linkages primarily involve engineering, sales, and service personnel from the supplier interacting with manufacturing engineers, purchasing, and maintenance personnel from the customer.

Transactions

Ruekert defines transactions as "exchanges of resources, work and technical assistance" between marketing and other groups.[19] This component of the theory clarifies "what" is exchanged as a result of the linkage or relationship- it defines the **content** of the linkage. In the context of our study, in which the linkage runs between supplier and customer firms, several kinds of transactions occur.

For example, manufacturers typically provide performance information, applications engineering assistance, training and other support activities relating to the sale of capital equipment to their customers. In turn customers often provide manufacturers with feedback on product performance, critique of the manufacturer's new product offerings, information on future requirements, and requests for product enhancements. These transactions may involve simple verbal exchanges between the supplier and the customer or significant partnering activities using beta sites or other arrangements.

[18]Ruekert, 4.

[19]Ruekert, 4.

In some firms, extensive vertical integration implies that the manufacturers and customers belong to the same company, as when one division supplies manufacturing equipment to another division of the same corporation.

Communication Flows

In order to effect the transaction, there must be a flow of information between the organizations. "Communication Flows" define "how" the transaction takes place and considers both the frequency and difficulty of communicating between the two parties.[20]

In the industry studied here, these linkages involve telephone, fax, visits to the customer's sites, visits to the manufacturer, meetings at trade shows, and the like. Although formal links (installation reports, after-sale questionnaires, regular meetings) are often used, informal contacts between manufacturers and the customer provide significant information. Several large firms have formal "customer visit programs" in which teams of personnel from the manufacturer (management, marketing, engineering, sales) periodically visit important customers to gain a broader perspective on customer concerns.[21] Frequency of contact is another important parameter of this communication flow. Selling capital equipment involves relatively infrequent transactions of high unit value and this means that suppliers must maintain many dormant relationships. [22] As a result, communication may occur with high intensity between buying, selling and engineering organizations around the sale period and then drop off dramatically until issues of service or new product needs arise as that customer's new equipment ages, or needs modification.

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[20]Ruekert, 4.

[21]Jakki Mohr, "Communicating with Industrial Customers," Marketing Science Institute Conference, Melbourne Florida, Report No. 89-112, (March 1989).

[22]Peter Turnbull and Jean-Paul Valla, Strategies for International Industrial Marketing: the Management of Customer Relations in European Industrial Markets, (London: Croom Helm), p. 212.

Coordinating Mechanisms

In the rubric used by Ruekert, "the coordination dimension involves formal working rules, the amount of influence a member of one unit can exert on a member of another, and the conflict resolution mechanisms used when either formal rules or informal influence fails."[23] Coordinating mechanisms, along with communication flows define the **process** component of the relationship.

I interpret this coordination function more literally in this study and apply it to the way in which the supplier-customer relationships are managed. For example, the sales organization and manufacturers representatives play a vital role for the supplier in coordinating a firm's interactions with the customer. Sales personnel are familiar with both the customer and the supplier organization and can coordinate the various resources to meet the customer's requirements. The customer's purchasing department often plays a coordinating role on their side of the transaction; however, once supplier-customer relations are established, direct contact between the supplier's engineering department and the customer's manufacturing engineering department is usually maintained.

Integrating the concepts

Up until now, we have discussed the importance of understanding and using customer needs in developing new products. We have also reviewed the concept of the product (technology) life cycle and have shown how suppliers of manufacturing process equipment can form linkages with their customers. Central to this study is the claim that capital equipment manufacturers must carefully consider their customers' product or technology life cycle in developing and maintaining linkages with these customers.

To understand the rather complex linkage issues surrounding the transition from THT to SMT in the electronics industry, I first consider a hypothetical example relating to

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[23]Ruekert, 4.

suppliers of metal working tooling for automotive assembly: Suppose that over the years, strong tooling supplier relationships develop with a major automobile firm, and suppose that the supplier's business grows handsomely as their few key customers enjoy strong market growth. However, suppose a few advanced assemblers begin using plastic components rather than metal. Our tooling supplier is so involved with its existing metal-based business that it does not form linkages with the new lead users in the plastics area. Even if some of its customers also begin dabbling in the new technology, the actual personnel may be different. (It may be an advanced R&D team rather than the manufacturing engineers who are trained with the metal working tooling that are involved with the plastics technology). As a result, the supplier is somewhat stuck: Although the firm's traditional linkages were beneficial in meeting the needs of their customers, the close relationships have prevented the supplier from developing new linkages necessary to track the natural life cycle of their customer's products which evolve from metal to plastic based technology. Consequently, it is vital for manufacturers to develop and maintain a broad array of connections with both existing and potential customers and to track carefully the natural evolution of their customers' requirements. This analogy will serve as a useful reference point for understanding a real example of this phenomenon to be discussed in the following chapters

Chapter 2
PRINTED CIRCUIT BOARD PACKAGING TECHNOLOGY

Overview

Before evaluating the role customer linkages have played in assembly equipment supply to the PCB industry, a brief discussion of electronic packaging is in order. The dominant form of interconnecting discrete electronic components such as resistors, capacitors, integrated circuits and the like has been the printed circuit board. Although many forms exist, the primary design includes one or more layers of copper clad epoxy board which are photographically imaged and etched to form various conductor patterns. The epoxy provides rigidity as well as inter-layer insulation whereas the copper circuit traces act as 'wires' between components.

Through-Hole Technology

In the traditional "through hole" printed circuit board holes are drilled through the conductor ends and then plated with copper, permitting the wire-lead of the component to be inserted **through** the board. A typical board might measure 8" x 12" and be "stuffed" or "populated" with nearly 50 components. After the components are inserted, the board is floated over a wave of molten solder which only adheres to the metal areas of the board and components, thereby forming an electrical interconnection. Typically, high speed automated assembly equipment is used to populate the board before wave soldering and such equipment, costing upwards of $100,000 or more per machine represents the most significant capital investment for a board assembler.

Surface Mount Technology

In response to shrinking component designs and the demand for smaller, lighter circuit board assemblies for special applications like digital watches, different schemes for

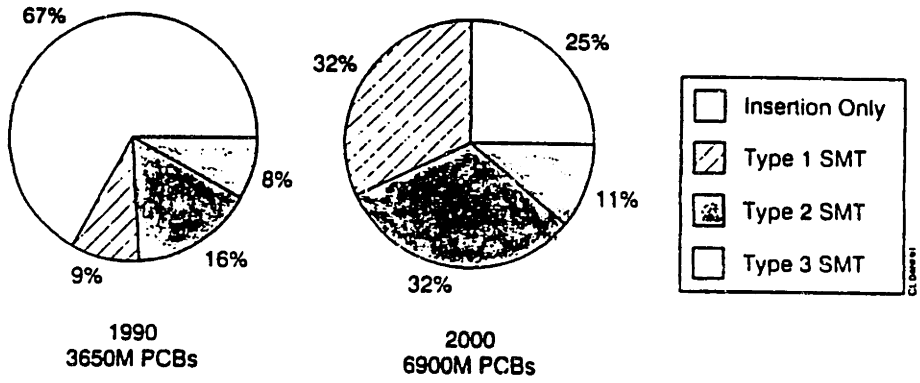
connecting components with one another have been developed. Partily because of limitations in the circuit board drilling process (hole location accuracy, minimum feasible hole diameter, minimum spacing between holes) and predominantly as a way of using PCB space more efficiently, a process in which components may be simply attached to the surface of a circuit board has evolved. This surface mount technology approach relies on small metal pads which are constructed at the ends of the copper conductor, on the board surface. Typically, small dots of solder paste are silk screened with high accuracy on top of the pads, and then components are carefully placed on the board often with a drop of adhesive to provide a mechanical bond. The board is run through a 'reflow' oven, in which the solder paste briefly melts and then rehardens, forming an electrical connection to the component. Various approachs to SMT assembly have been used, and high speed automated assembly equipment costing $100,000 to $500,000 per machine are currently marketed by several firms.

Board Packaging Transition

Through hole and SMT today represent the primary methods by which electronic components are connected with one another to form a system or part of a system. Whereas THT techniques have been used for over 30 years, SMT really only began in the United States in the 1970s and is rapidly increasing its share of the board packaging market.

During the transition phase, which is still underway, hybrid designs are frequently used, in which both through-hole or 'insertion mount' components and surface mount components are used on the same board. Figure 2 below depicts the 1990 data on the packaging mix for various types of hybrid assemblies as well as a forecast for the year

2000. The forecast predicts that whereas 67% of all printed circuit boards assembled in 1990 are pure through-hole type, by 2000 only 25% of all PCBs will use this technology, and 75% will incorporate some form of surface mount design.[24]



Key:
Type 1: All surface mount components
Type 2: Through-hole and surface mount components, top side.
Type 3: Through-hole components, top side; surface mount components on bottom side.

Figure 2: Packaging Mix Forecast

The transition from THT to SMT provides a fascinating example of product and process change in a dynamic industry. On the one hand, "raw materials" suppliers of chips continue to shrink the component sizes, as end user products such as cellular

[24]Information and Figure courtesy of BPA Inc., Cold Spring Harbor, New York.

telephones, radar detectors and certain military equipment demand smaller, lighter circuitry. But on the other hand, board manufacturers must continue to provide interconnection schemes which provide a smaller platform for even tinier components.

The lack of standards in the early days of SMT has added to the confusion in the industry, making it difficult for production equipment suppliers to risk major new development efforts.[25]

Implications for Suppliers of Automated Assembly Equipment

Regarding the industry of interest for this study, manufacturers of automated board assembly equipment have also been forced to provide machines that can place components onto SMT type boards, a process far more demanding than the traditional THT equipment business has been.

One of the major advantages of SMT is that the techniques have evolved as much more of an integrated process than THT.[26] In the past, through-hole insertion machines functioned as 'islands of automation' with little integration with the rest of the factory required. Today however, a surface mount pick and place machine for example is an integral part of an automated assembly line, involving central software control, on-line statistical process control (SPC), coordination with solder paste screening operations, etc. Moreover, the smaller SMT component sizes have forced machine manufacturers to develop innovative parts handling schemes, advanced vision systems to check component orientation before mounting, and higher throughput speeds.[27] Finally, the advent of SMT assembly systems has changed the shop floor economics of board

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[25]Gary G. Peterson, "Standards for Surface Mount Technology: Where we Stand," Electronic Business, (March 6, 1989): 113-114.

[26]John Krukowski, "Implementing SMT: A Painful Rite of Passage for Board Assemblers," Electronic Packaging and Production, (October 1989)

[27]Philip Newbury, "Surface Mount Assembly Machines," Electronic Packaging and Production, (June 1990): 38-39.

assembly. Purchasing decisions involve more of a systems perspective now, and so the choice of an SMT pick and place machine is more dependent on the other capital equipment required for the process.[28] We now focus on this SMT product innovation and examine how automated assembly equipment suppliers' linkages with customers have evolved with this major transition in process technology.

[28]Charles-Henri Mangin, "Surface Mount Changes Shop Floor Economics," Electronic Packaging and Production, (September 1989): 112-114.

Chapter 3
THE EMPIRICAL EVIDENCE

Four firms engaged in the manufacturing of automated assembly equipment were studied in order to determine empirically the role manufacturer-supplier linkages play in this industry's evolution from THT to SMT printed circuit boards. After presenting a brief overview of the research methodology used, I report the results of the research in two parts. In Part A, I demonstrate how the firms actually obtain the voice of the customer in developing automated assembly equipment. In Part B, I consider each firm in turn and identify how these supplier-customer linkages have evolved as printed circuit board packaging technology shifts from through-hole technology to surface mount.

Research Methodology

The methodology used in undertaking this study has been relatively straightforward. To gain an understanding of organizational communication, the social science literature has been reviewed. In particular, I have focused on the body of literature that addresses how people communicate both within and across firms. Further, I have explored several areas of the marketing literature which examines the product life cycle, product innovation, and the ways in which firms form relationships with their customers in industrial markets.

On the technology side, I have investigated the popular trade journals (Electronic Business, Electronic Packaging and Production, Surface Mount Technology) to gain some background on the assembly equipment industry.

Finally, the bulk of the empirical evidence was gathered from interviews with professionals in the industry. I have visited three of the four firms investigated, conducted telephone interviews with employees of the fourth firm as well as with several customers, and have visited at least one customer site. In sum, 30 interviews were conducted over a three month period. Personal interviews generally lasted 45 minutes and telephone interviews approximately 30 minutes. In most every conversation, participants welcomed the opportunity to share their views provided that the results were aggregated and not associated directly with that person or firm.

In the course of this study, every effort has been made to represent fairly the interview results and to discuss objectively generalizations about each firm studied. However, in a project of this limited scope it is very difficult to show conclusively how supplier - customer linkages have helped or hindered equipment manufacturers in their efforts to make the transition from through-hole to surface mount type assembly machines.

Consequently, the following caveats must be considered in reviewing the results presented below:

1. Research Balance:

   The number of interviews held at each firm varied both in duration and scope due to scheduling and time commitment issues. Future research should strive for a more comprehensive examination of each firm studied.

2. Primary Focus:

   The customer's perspective was not fully explored. A few users of this type of equipment were polled and one facility was visited in order to gain background information; however, this thesis has focused primarily on suppliers of component assembly equipment.

3. Firm Balance:

The four firms analyzed are quite dissimilar both with respect to market position, extent of product line, and history in this industry. In general, an effort was made to examine a variety of supplier types- large and small; full line and niche player; newcomer and old-timer. Consequently, the major findings, presented at the end of this study are derived from a rather diverse sample of firms and so any general model presented may not fit one particular case in all respects.

4. No Control Variables:

A major drawback to a study of this type is the difficulty of controlling important variables. The evolution of board assembly technology is occurring concurrently with numerous changes in manufacturing practices, organizational design and production philosophy. As a result, the ways in which these firms have managed their linkages with customers during the THT - SMT evolution have really been in response to many factors, not just the advances in board packaging technology studied herein.

5. Objectivity of Responses:

A great danger in focusing on a topic like "customer linkages" is that when questioned specifically on the topic, firm respondents are likely to embellish their responses (that their firms are very customer-oriented in this case) because they naturally want to "please" the researcher. In another study, a broader line of questioning might reduce this tendency however based on this effort's narrow focus, it was necessary to be very specific.

Research Results

In Part A below, the ways in which firms in this industry form relationships with their customers is described. In general, the linkages emerge from the firm's efforts to capture the voice of their customers in developing and selling new board assembly equipment. In Part B, Supplier-Customer linkages are discussed for each of the four firms studied in this project. For each firm, I have devised a suitable name and description which captures the essence of the company's transition to SMT. Thereafter, I present a brief history of the firm's product development efforts and then discuss linkages along major functional lines (Sales, Marketing, Research-Development-Engineering (RDE).) The following Chapter then examines the findings as a group and presents several major conclusions regarding this studies' premise that successful firms must manage their customer linkages in accordance with the evolution of the end products' life cycle.

Part A: Voice of Customer in the Firms Studied

In the course of this research, a critical test was to determine how firms learned of customer needs and incorporated this feedback in their equipment offerings. Indeed, an understanding of this provides a basis for the supplier-customer linkage, which, according to my hypothesis, is an important factor in making the transition from through-hole to surface mount board assembly.

Generally speaking, the automated assembly equipment suppliers gathered customer input through a variety of forums ranging from traditional market research to strategic placement of prototype equipment in prospective customer plants. No effort was made here to assess the relative importance of each link; rather this section qualitatively describes the various forms suppliers actually use to gather these inputs.

Market Research

The firms examined depended on technical journals and trade publications to keep up to date on industry events; and various surveys and internal reporting schemes (lost order report, service records) to gather information from existing customers. The firms also gather such information by closely watching competitors' offerings, with the hope that the competitor has perhaps uncovered an unknown but critical customer attribute.

Trade Shows

Involving more personal contact, trade shows were cited by every firm interviewed to play a critical role in both devising new equipment and in gathering feedback from customers on key developments. One firm, for example, sent a new advanced machine to NEPCON West along with seven engineers to chat informally with prospective customers and to glean feedback and suggestions for future improvement. Another manager interviewed likened NEPCON to a reunion of sorts, in which firms invite their colleagues to hospitality suites, and renew old ties, as in many ways this industry is somewhat of a "small society" in which participants may switch firms, but maintain strong contacts with one another. In a word, such informal networking can be a powerful way for suppliers to receive important information on customer needs.

Partnering Programs

Each firm interviewed has developed some form of partnering program with certain members of its customer base. One customer interviewed was thrilled with the attention he received from the equipment supplier, mentioning that several suggestions that he (and presumably others) had made were actually incorporated on the next generation machine offered by that supplier. Another firm invites 20 customers every six months to a two day 'Technology Advisory Board' meeting in which the future needs of the market are discussed and participants provide comments on existing equipment in the field.

Beta Sites

Most participants in the study rely to a great extent on some form of field trials or beta site testing before releasing new products to market. In such an arrangement, the supplier places the new machine into a customer's production facility, and the equipment is run extensively to uncover any weaknesses and provide feedback for future improvements. One firm mentioned the use of "Alpha Site" testing as well, in which a primitive prototype is delivered to a customer in order to define better the customer's attributes (for example, where to place an emergency stop button).

The use of testing sites is a very attractive way for suppliers to incorporate the voice of the customer in new product offerings. Such field testing allows the supplier to maintain a strong engineering presence at the customer, thereby developing personal relationships as well as a strong understanding of the user's production environment. It also fosters goodwill in the eyes of the customer- a powerful lever for future sales activity and word of mouth promotion.

Vertical Integration

Perhaps the closest link to ones customers was discovered in some of the larger Japanese firms in which the equipment supplier and customer are part of the same corporation. Although this study does not directly encompass this link, some evidence suggests that certain equipment suppliers are able to get very close to their "customers needs" because they supply the process equipment to the board assembly division of the same corporation.

Part B: Discussion of Linkages by Firm Studied

General Pattern

The primary finding with regard to the linkages that AESs form with their customers is that the supplier may become so closely aligned with its core technology and existing customer base that it is unable to develop new linkages, a process vital to their competing successfully as the product life cycle evolves.

Although each firm studied has to some extent recognized this problem and has taken steps to develop the necessary new relationships to succeed, their experience has, at best been painful, as their early attempts at supplying new SMT assembly equipment met with discouraging results and allowed outside competitors to capture significant market share.

I now turn to a discussion of the pattern peculiar to each firm studied, the details surrounding the customer linkages formed, and finally, a summary chart which highlights the primary findings for this section.

Firm A: "Faithful"

The first firm we study would best be labeled "Faithful" with regard to its transition from through-hole technology to surface mount. Faith has a long history of close customer ties in the electronic assembly business. In fact, its early entry and spectacular growth directly resulted from the good fortunes of its first few customers in the THT market. In the early days, Faith executives had close relations with the early customers' executives and in fact even the very identity of this firm seems to have been closely tied to its loyalty to a few select users. As the THT market blossomed through the early 1980s, Faith's traditional customers demanded product enhancements and extensions which, according to nearly every manager interviewed, "cost us focus on SMT."

In some ways, the traditional customer linkages were beneficial in alerting Faith to the changing market needs as several existing as well as new customers approached this firm for assembly equipment solutions for SMT. But, the firm claims to have not had sufficient resources to address this nascent market, and furthermore component and assembly standards for SMT were very fluid at that time- the tremendous flux in the packaging industry made it very risky for a firm to develop a new SMT machine. In short, this firm remained faithful to its core markets, perhaps at the expense of its long term health.

Another factor leading to Faith's difficulty in meeting its customers' SMT needs has been a sort of technical arrogance. The firm's very success in developing a strong customer base and becoming a leader in THT equipment may have caused her to underestimate both the demands of the SMT process and the fierce international competition.

Consequently, even today after several false starts this firm is struggling to supply a competitive high speed SMT assembly machine. Nevertheless, this painful experience in trying to meet the changing needs of customers over the PLC of board packaging

has been very instructive to this firm. In a way, Faith's story typifies the general pattern found in this industry, and an examination of these linkages shows several ways in which a supplier can modify its relationships with customers in order to meet the changing requirements of the marketplace.

Sales Link:

Originally, sales personnel from this firm focused on the existing as well as new customer needs in THT. Contacts were through the buyer's purchasing department as well as manufacturing engineering group which was the primary decision-maker on equipment selection. The link was often very narrow, and even larger accounts focused on only one or two people at the customer. In effect, this linkage merely provided quotes to the customer and coordinated the transfer of information.

Today, the firm has recognized the need for a much broader set of links with the customer and has set up an improved selling philosophy in which the account representative must develop relations with a range of customer personnel generically listed as follows:

User Payer Decider
Mentor Affected By
Key executive
Ace

It is interesting to note that this change has been driven in part by the rise of concurrent engineering and interfunctional team building in industry today. As customers now include a wider array of people in the equipment selection process as part of manufacturing work team approaches, so too must suppliers consider a broader array of users in selling the equipment. Furthermore, the entire company has received some training in this kind of selling, and so in the context of other functions (engineering, service, etc.) there is now better recognition that wide linkages with the customer are necessary.

Marketing Link:

In the past, Faith's marketing was fairly weak. The technical direction was often set by the "noisy customer." As such, product strategy was largely reactive: Customers demanded various solutions and the firm evaluated and acted upon those needs that seemed to present the broadest opportunity. As the noisy customer often comprised Faith's traditional THT equipment base, the firm had little market access to emerging trends such as SMT.

Today, Faith is establishing key supplier partnering programs. With one key customer, for example, Faith participates in a monthly video conference in which a business manager, marketing engineer, technical specialist, and salesperson from their organization 'meet' with various technical and management personnel from the customer. The goal is to focus 50% of the meeting on existing equipment issues (reliability, performance, enhancements) and 50% on future needs. Although such linkages risk Faith's getting too focused once again on one customer's particular needs, strategic selection of partners here may improve the firm's ability to anticipate evolving market needs.

Research, Development and Engineering (RDE) Link:

An examination of customer linkages with Faith's technical personnel provides a particularly rich example of the need for relationships which evolve with the life cycle of its customer's products.

As mentioned, the evolution from THT to SMT has required more of a manufacturing process solution rather than simply an equipment product offering. Now AESs need a broader skill base to help their customers achieve high yields. As a result, Faith has had to acquire new expertise and then form completely new linkages with different personnel at the customer. Whereas in the past, Faith engineers had links to manufacturing engineers at the customer, now new R&D personnel at Faith who possess process knowledge (skills in physics, material science, thermodynamics) have

connections with advanced manufacturing engineers at the customers who can come in and evaluate process issues in advanced laboratories only recently available at this supplier. In short, the major technology change required by SMT has necessitated the forming of substantially new technology links. The customer has become more technologically sophisticated as his product has evolved and so too must the supplier.

Faith has also modified its customer linkages through strategic hiring. In a new Fine Pitch machine project, the firm was about to go to market before the equipment was fully developed.[29] The machine was technically advanced and well received at a trade show but lacked critical ancillary features. Shortly before launch, a new director of the program was hired. He happened to have been sales director of a specialty assembly equipment supplier. Because of his extremely close customer knowledge from his prior position, he was able to supply the missing link between Faith's technical group and the largely new potential customer base. The ensuing major product modifications and repositioning is currently showing strong promise in the marketplace. Had this new personnel linkage not been formed, some argue that Faith would have missed this product evolution as well.

A final key component of developing links with customers is the use of beta site field trials. By supplying advanced equipment to a few lead users Faith has been able to gather invaluable production experience, forge close working relationships with its customers, and thereby include the real voice of the customer in its more recent product offerings. As with the partnering program, if Faith can select the right 'lead users,' the linkages will help rather than hinder the process of meeting changing customer requirements.

[29]Fine Pitch relates to an more refined electronic assembly scheme, which requires even more precision than SMT.

Firm B: "Careful"

The second firm examined would best be called "Careful," as a way of characterizing its transition from THT to SMT equipment development. As a niche player, supplying a myriad of board assembly aids including manual and semi-automatic equipment, Care has maintained a reactive posture in moving its product line to SMT applications. The Firm sees SMT coming and is developing SMT assembly solutions, but tends to respond to specific customer requests for new products rather than develop new offerings on its own. In this case, Care is 'trapped' by its traditional THT customers in another way. A small firm with limited resources but a healthy THT demand to date, Care is unable to assume the risks of a major SMT program. Traditionally, the firm has forged close ties with a few customers in accepting contract machine development work that promised broader applications and a good fit with their existing technology. The manager's interviewed here said, however, that their SMT customer tend to be different than their traditional THT customers: Even if it is the same firm for both SMT and THT, the manufacturing engineers involved are typically different personnel, and so Care's personal relations with their customer's THT people have not generally been useful in sparking new SMT opportunities. In summary, this supplier is also experiencing difficulty in making the transition from THT to SMT, in part as a result of its traditional ties with THT customers. The firm sees SMT as inevitable, however, and is trying to follow the evolution of board packaging technology in a careful and sensible manner.

Sales Link:

Care relies to a large extent on applications engineers to make sales. These personnel serve a vast number of customers, working at the customer site as well as in the demonstration center and labs available at the home office. Their primary link is to customer manufacturing engineers and purchasing departments. Care's applications engineers are active at trade shows as well as conferences and seminars and provide an important link between the market and the firm's engineering department. It

appears that this firm's sales-customer linkages have remained steady with the advent of SMT, and the firm has had to work harder developing new linkages with the customer personnel who are beginning to work in surface mount.

Marketing Link:

In this firm, the distinction between sales, service and marketing is somewhat blurred as the staff is quite small. However, marketing at Care tends to have strong links with existing customers through its added responsibility for coordinating service and responding to customers' performance questions. As a result, planning for new products in SMT has relied to a large extent on technical journals, trade shows, competitive benchmarking and feedback from manufacturing representatives. Despite the danger of missing major SMT opportunities offered by new players in the board assembly business, it appears that Care will eventually benefit from its existing customer base as those customers themselves are forced into SMT.

RDE Link:

Care has a central engineering department which works closely with the applications engineers and specific customers in developing new equipment. The firm is driven by a very strong design philosophy which emphasizes simple machines, solid value, and relatively low cost product offerings. Their products satisfy a market need for the smaller board shops which do some manual assembly and have strong low volume military and prototyping applications, for example. It seems that this design and product focus is the overriding factor governing the way in which Care is now moving into SMT products and so it is difficult to speculate on the role RDE customer linkages play in this transition.

Firm C: "Hopeful"

The third firm studied can best be characterized as "Hopeful" in its efforts to make the transition from THT to SMT. The firm has a long history of providing automated assembly machines but faced serious field problems as it tried to lead the market with an early SMT offering. Forever optimistic, Hope has learned from experience to listen to the sometimes very loud voice of her customers and incorporate this feedback into future machine designs. Today, the firm takes much more of an interfunctional approach to equipment design, marketing and manufacturing, so that the product offerings better fit their customer's needs and so that new solutions can be brought to market more quickly. For example, a customer contacted for this study said that an early Hopeful SMT machine was difficult to fix, requiring the service technician to assume uncomfortable positions to make the repair. Today, a regional sales manager for Hope, in discussing the firm's more recent SMT product line said emphatically that the new machines contained no "contortionist items!"

In terms of the general pattern, this firm too was grounded in a successful THT business and was technically somewhat arrogant by assuming that it could rapidly sweep the SMT market as well. However, faced with poor new product performance in the late 1980s and worrisome customer backlash, Hope has had to reassess the way in which it brings new products to market and now appears to be much more customer driven. In this example, then, we see a firm that has confronted the transition process with optimism despite challenging early setbacks and as a result is better positioned for the future.

Sales Link:

Hope's sales link fits the traditional pattern of involvement with the customer's manufacturing engineers, buyers and management. However, the firm has undergone many changes during the transition period from THT to SMT and so it is difficult to trace the evolution of the sales - customer linkage. At one point during the transition,

Hope bought a foreign R&D firm which supplied their early SMT equipment. Despite strong initial acceptance by several large US computer manufacturers, Hope supplied poor service and weak product follow-up. Somehow, the voice of the customer was lost, perhaps due to poor internal linkages (product development was done abroad, served by the local organization) and so the feedback which is especially important early on in a product's development cycle was lost. As the salesforce plays a vital role in communicating customer needs back to the firm, it appears that the sales linkage was weak at this time.

Today, Hope has brought its SMT product development efforts back to the United States and employs a sales force with broader skills. Whereas in prior years, sales personnel were primarily professional salesmen, today Hope's salesforce includes former marketing and service people as well.

As discussed in Faith's case, an SMT machine sale involves more than quoting price and delivery, and so firms moving into SMT need a much broader sales linkage with increasingly more players at their customers firms. Clearly, a sales team with marketing or service background can better relay customer feedback to the home office.

Marketing Link:

Hope gathers marketing input in a way similar to the other firms. Personal meetings are held with important customers and their advanced manufacturing groups and future requirements are carefully discussed. Moreover, this firm of late brings customers into the home office to examine and critique new SMT machine offerings. The manager interviewed mentioned that this practice was particularly helpful in evaluating and improving software features.

RDE Link:

Some firms in this industry have managed the technical shift to SMT by acquiring substantially new process knowledge. New links were formed, perhaps between

advanced manufacturing people at the customer and newly hired chemists at the supplier, for example. In Hope's case, there seems to be more of a shift in organizational philosophy as the firm moves into SMT. I do not claim that there exists a cause - effect relationship here, but nevertheless, Hope has adopted more of a concurrent engineering model, using interfunctional teams which include a marketing manager, buyer, manufacturing engineer, development person, as well as support from field service and sales. These teams have their own work area and so internal communications are vastly improved. The firm has consequently enjoyed shorter development cycles and substantially lower costs to name a few benefits of this organizational approach.

The research done to date provides little hard evidence on how these teams now interact with the customer. However, one can speculate that by improving internal communication, Hope will have a much better change of acting upon any information that does come in from the outside through the sales channel, for instance.

Hope also has developed much closer ties to the component supply industry with the advent of surface mount. By participating in standards committees in electronic packaging, Hope not only has some influence on component design, but also maintains ties with a direct information source concerning next generation components that their machines must be able to handle in the future.

Firm D: "Youthful"

In contrast to Faith, Care, and Hope, this firm is a relative newcomer in this industry, having had no history in THT technology. For lack of a better adjective, "Youthful" signifies this maturing company's perhaps fortunate position as an SMT-only assembly equipment supplier. Youth was founded to fill a niche in the market for low volume but high component mix equipment and achieved rapid early acceptance because of its unique product line. We study Youth in order to test the hypothesis that firms originally based in THT have had trouble in SMT because of their strong THT customer linkages. Although the early evidence suggests that the innocence of Youth in a way fostered a very strong early product offering, we find that with the onset of adolescence, this firm too is facing difficulty in adapting to rapidly changing markets: As SMT is beginning to mature, standard customer needs are becoming well-established and so a once differentiated product is less attractive to customers who are more apt to demand increasingly similar high volume, medium to high component mix machines. One interesting trait of Youth is that she, perhaps more than her grown up competitors has recognized the importance of links to component suppliers and other firms working at the forefront of component packaging. Such relationships are especially critical in SMT as the success of this technology depends on strong coupling between the component design and the machines that place them on the board. Analysis of this firm suggests that linkages other than with ones traditional THT customers play an important role in a supplier firm's ability to offer successful SMT assembly equipment.

Sales Link:

The role of Youth's sales team is similar to the function performed by other suppliers' sales activities. Sales initiates the call and develops ties with the customer's manufacturing engineering department. The sales team also must get to know all the key players in the customer's organization as the decision making unit may comprise several people. For smaller customers, this may even include the President or Vice

President of the firm for example. It is interesting to note that Youth's organization is very open to direct engineering or marketing links with the customer as the firm is small and informal. In some firms, Sales plays a much more active role in coordinating and controlling the organization's contact with customer personnel which can inhibit engineering-to-engineering interaction. Youth's small size and openness to broad customer contacts may therefore help the firm better track future changes in the board assembly marketplace. On the other hand, as Youth matures, more formal organizational structures may inhibit this mechanism.

Marketing Link:

It is difficult to characterize this firm's marketing link to its customers as there is considerable overlap among marketing, sales and engineering. The firm has less than 100 employees and so tasks are not so clearly differentiated here. Youth is working hard at developing its reputation and brand recognition; it is leveraging off trade shows, developing strong beta site relationships, and sponsoring periodic user group meetings with its established customers. In a way, Youth is free of the burdens of supporting a maturing THT market, but faces the equally daunting task of establishing itself as a mature and serious contender in the SMT business.

RDE Link:

As found in the other firms studied, Youth develops new equipment using groups of engineers and designers who create a specification using input from sales and marketing, and analysis of competitors' offerings. The engineering manager interviewed also cited strong direct links between a handful of customers and Youth's engineering staff. For example, one customer programmer became somewhat enamored with this supplier's software and often telephoned Youth's software developer to make recommendations. The small size of Youth's firm and its informal style seems to have encouraged such customer participation.

A particularly interesting technical link that Youth enjoys is a relationship with a neighboring supplier of chip packaging equipment. It turns out that almost one third of Youth's engineering staff were prior engineers for this other supplier and maintain informal contacts there. For example, during the development of a new assembly machine Youth's engineers noticed that their neighboring equipment supplier was beginning to ship larger machines. Because of the relationship and knowledge of this other firm's business, Youth was able to capture somewhat of a leading indicator for component packaging, and modify their assembly equipment accordingly. (The larger chip packaging equipment in this case indicated that discrete components were getting larger in this industry, implying higher lead counts, and therefore added sophistication required of the component assembly machines.) Other assembly equipment suppliers that have only more formal relationships with component suppliers may not capture such information as readily.

Thusfar, we have examined how four firms have managed their linkages with customers as board packaging evolves from THT to SMT. To summarize these findings, Figure 3 presents a chart which covers the main points of this discussion. In the following Chapter, we present the overall findings of this study.

Firm \ Function	Sales	Marketing	RDE
Faithful Loyal to TH at the expense of SMT. Difficult transition to SMT. Creating New Linkages	Narrow Link (Quote price & delv.) ↘ Broad Link (Ties with wider set of Decison makers.)	Noisy Customer (Reactive Approach) ↘ Now Marketing (New partnerships with key Customers)	Product Knowledge (Narrow Skills) ↘ Process Kldg. (New skills & links.)
Careful Cautious in moving to SMT Reactive mode to evolving needs of TH Customers	Fairly steady application engineering link to traditional TH customers SMT forcing formation of new linkages.	Combined Mkt & Svce Key data from jounals, trade shows & customer feedback SMT is forcing firm to gain new knowledge. Reactive	Driven by Design philosophy New links formed, ad hoc basis Impact of SMT unclear
Hopeful Difficult early transition to SMT. Now learning from experience and optimistic for future	Traditional Sales Quote price & Delv. ↘ Broader Skill base in Sales Wider Customer linkages	Meet with Key Customers In-house equipment evaluation by customers Matrix organization-Facilitates internal communication of Mkt. input	Three Step Transition In-house attempt ↘ Buy SMT Tech from outside ↘ New internal organization
Youthful New Participant in Industry. No TH Experience. Building on Innovative Linkages	Strong ties to customer manufacturing engineers and other decision makers Informal about other function's linking to customers	Small Firm: Overlap with other functions Need to develop reputation Link to Customer via user groups	Typical use of sales org. for feedback; Strong direct links to Customer Powerful collateral links with other supplier (chip eqp)

Figure 3: Summary Chart of Firm-Specific Findings

Chapter 4
MAJOR FINDINGS

In this Chapter, I consider the information gathered from all the firms examined and present the most important themes relating to supplier-customer linkages and the product life cycle. In short, the evidence suggests that to survive, firms in the industry studied have been forced to manage (change and modify) the linkages that they develop with customers as their customer's needs evolve over the course of the product life cycle. Especially when a technology such as through-hole is in the maturity stage (See Figure 1) and alternatives such as surface mount are in the development or growth stages must supplier firms be particularly active in modifying their external linkages in this industry. Once more we return to the framework established in Chapter One and consider the results in terms of **Transactions, Communication Flows,** and **Coordinating Mechanisms.**

Transactions

Recall that this dimension of the model denotes the **content** of the supplier-customer linkage. The results of this study indicate that supplier firms have had to incorporate new skills and technology in serving the rapidly changing needs of the customers. Whereas a traditional THT customer interaction might have involved a specification for assembly machine accuracy, for an SMT application, the interaction would also consist of a specification for downward placement force and vision system software performance for example.

As such, the life cycle evolution from THT to SMT products has forced a major technological shift on assembly equipment suppliers. The demand for supplying a

manufacturing process rather than simply an assembly machine means that suppliers must acquire significant new technical expertise and modify their traditional relationships with customers to include the new technology in the transaction.

Since not all AESs have the resources to develop or acquire new technical process skills for SMT, these firms must also develop new linkages with other suppliers, as discussed in Chapter 5.

Communications

The process by which suppliers and customers communicate has not changed appreciably as board technology has progressed from THT to SMT. Telephone, fax, and personal meetings are the norm. However, "who" communicates with "whom" is a most important change discovered in this study. Supplier firms have had to form linkages with many new entrants in the board assembly business.

In particular, the firms which form the manufacturer's customer base play a critical role in this problem of linkages and the product life cycle. Although forming close ties to ones customers seems to be the most sensible way to capture key user needs in ones products, there is indeed a danger of myopia. Supplier firms need to be open to forming new linkages with other, perhaps very different customer firms in order to track important industry trends.

Not only are new company links vital in this process, but also, the transition from THT to SMT has required **different personnel** in supplier and customer firms to communicate: Supplier-customer linkages by definition denote relationships between people. As the end products evolve and the base technologies change, so too do personnel requirements. From the firms studied, it has often been the case that supplier firms have hired people into key positions who have an existing network with the new lead customers. In addition, the increased technical content of the transaction has clearly forced supplier firms to develop new technical linkages with their customers. Rather than simply an engineering - engineering interface, the linkage now involves

advanced manufacturing people from the customer linking to process scientists at the supplier who have access to advanced laboratories, for example. As such, communications between suppliers and customers now may involve new companies as well as different personnel. Forming communication links with other customer companies and different personnel in those companies is therefore an important way for supplier firms to manage their customer relationships over the product life cycle.

Coordinating Mechanisms:

This other part of the process component of the system-structural model has not changed significantly either as customers in this industry shift to SMT. Sales and purchasing departments still play an essential role in coordinating transactions between the firms. However, the process has become more complex: The move to interfunctional teams in product design, or manufacturing committees in equipment procurement has increased the number of people and functions involved in specifying and selecting manufacturing process equipment. Sales personnel need to develop linkages with a broader cast of characters at the customer as well as provide feedback to multi-disciplinary engineering teams at the home office.

The increase in complexity here does not directly stem from the THT to SMT evolution. Rather, changes in manufacturing and design philosophy have occurred in parallel with the changes in board packaging technology. Regardless of the cause-effect relationship, SMT as practiced today is clearly more of a manufacturing process than through-hole technology was. The highly integrated SMT production line and increased level of process technology places greater demands on the coordination of linkages between suppliers and customer firms and this has been reflected in new approaches to the sales activity by the major equipment suppliers analyzed in this study.

Chapter 5

ADDITIONAL FINDINGS

In addition to the finding that firms must manage their relations with customers as new end products evolve, I have found that supplier firms must also forge new relationships with other kinds of firms or agencies in order to meet changing product needs.

Through-Hole Technology Linkages

Figure 4 below depicts the typical kinds of linkages that an equipment supplier of THT assembly machines would use to develop, market, and service its products. Up until now, we have primarily focused on the Equipment Supplier - Customer linkage, but have also alluded to other external relationships as depicted in this Figure.

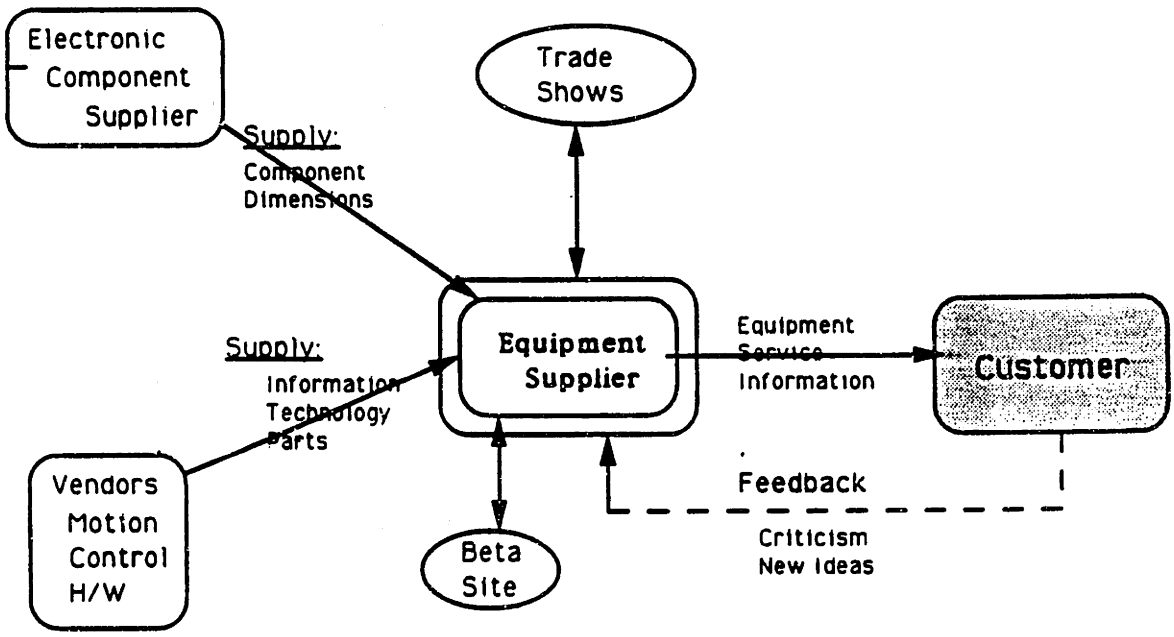

Figure 4: Through Hole Technology

In tracing the ascendance of SMT in the context of customer linkages, I have also shown that the historical order of many of these THT linkages has been disrupted. Moreover, the difficulty that equipment suppliers have had in developing new and more complex relationships has resulted in new competitors' taking market share away from the firms studied. The primary additional findings of this study therefore relates to the other, collateral linkages that suppliers must form to compete effectively in the new surface mount technology.

Surface Mount Technology Linkages

Generally speaking, the equipment suppliers have retained the kinds of ties they held in THT shown in Figure 4. But, as shown in Figure 5, the emergence of SMT has forced the equipment suppliers to develop new relationships as follows:

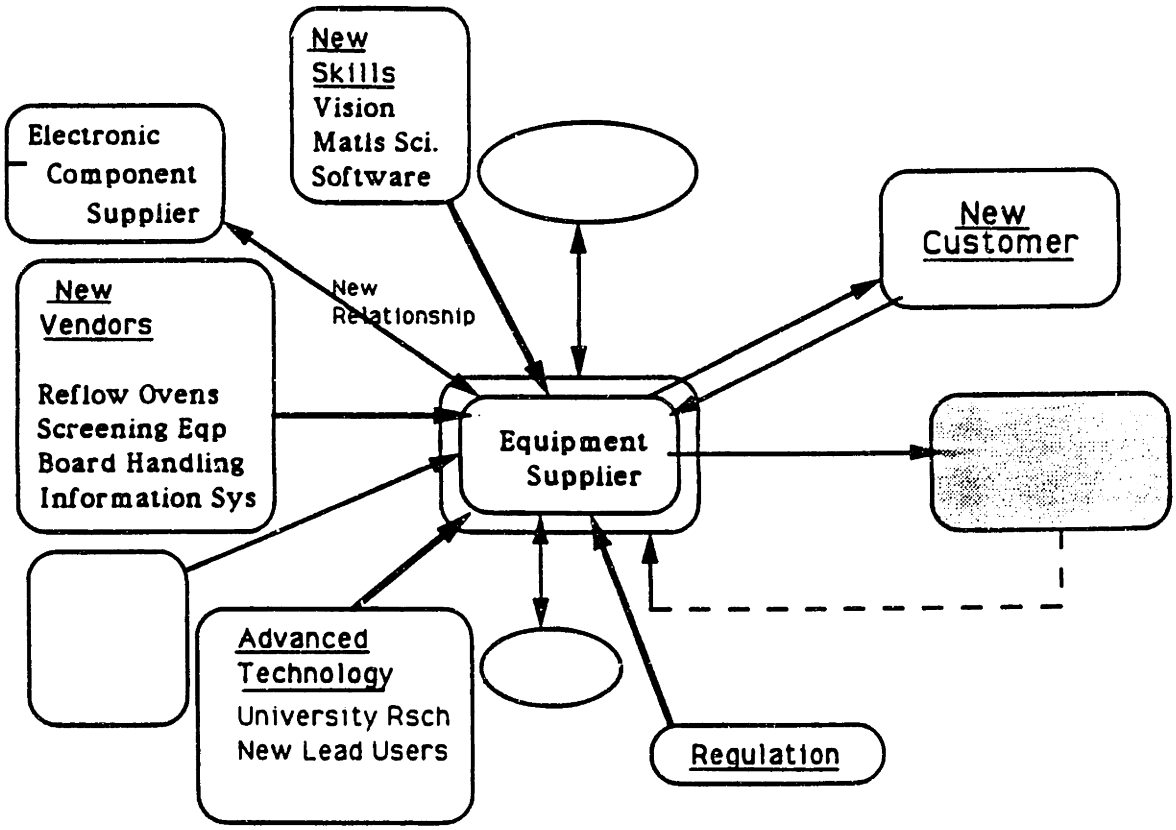

Figure 5: Surface Mount Technology

SMT involves other technologies requiring expertise in vision systems, materials science and software to name a few and so equipment suppliers have been forced to align themselves with providers of such new skills. In addition, electronic component suppliers and the equipment supplier are now much more interdependent, as some of the new SMT components are so small that they can only be placed automatically. SMT is much more of an integrated assembly process than THT, and so equipment suppliers must have ties with other new vendors as well. The rate of change in the electronics industry today implies that equipment suppliers must form ties with people in advanced technology and new lead users. Moreover, new environmental concerns are threatening the soldering process, the heart of board assembly, and so equipment suppliers must keep current on regulation.

The Future of Linkages in this Industry

Using Figure 5, this section elaborates on the collateral linkages that suppliers must form in the areas of: New Skills, Electronic Component Suppliers, New Vendors, Advanced Technology and Regulation.

New Skills

The nature of the surface mount process has resulted in the development and application of several new technologies in which traditional THT equipment suppliers had little or no expertise. As I have shown in the "Major Findings" Chapter, New Skills are critical to the "Transaction" between suppliers and customers as the industry moves to surface mount. But in a broader context, new linkages with people and firms possessing these new skills necessary for successful SMT development is also critical.

Electronic Component Supplier

Whereas with THT equipment suppliers had relatively weak relationships with suppliers of components like chips, resistors, and capacitors, SMT has forced much tighter coupling along these lines. Indeed, highly successful Japanese SMT assembly machine manufacturers such as Panasonic and TDK got into the business because their firm's

chip component division needed reliable equipment to assemble increasingly smaller parts into consumer products. The high degree of vertical integration of these firms provided this critical link. Although equipment suppliers have always needed some ties with the component suppliers, the evolution to SMT has forced equipment suppliers and component suppliers to work more closely together.

New Vendors

Through-hole technology insertion machines typically functioned independently as "islands of automation." A board shop could purchase its equipment from a variety of vendors and not have to worry much about integration. SMT benefits, on the other hand, from much more of an integrated process approach in which a complete assembly line is under computer control, with each machine automatically gathering statistical process control (SPC) data and in which boards are automatically moved from one machine to another. Consequently, many new linkages have sprung up throughout the equipment supply industry here, and the firms that are best able to manage their supplier relationships and provide the customer with a true SMT process will succeed.

Advanced Technology

Speculating about the future linkages required of equipment suppliers for a moment, advances in assembly processes and electronic component packaging may certainly threaten even the most successful producers of SMT assembly equipment unless they forge some ties with people working at the forefront of advanced technology.

In the short term, researchers are attempting to eliminate the soldering process altogether: Solder contains lead which is toxic, and the present techniques for post-solder cleaning use CFCs which damage the Ozone layer. Moreover, the high temperature solder reflow process can damage sensitive components. Conductive epoxies provide an attractive alternative for SMT assembly,[30] and Emerson and Cuming,

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[30]Art Buckhard, "Conductive Polymeric Adhesives Solve SMT Assembly Problems," Adhesives Age (October 1990): 36-39.

a division of W.R. Grace recently developed a product called Uniset LC-68 which is a screen printable silver filled electrically conductive adhesive.[31] [32] Currently, equipment suppliers have little or no coupling to the research efforts of such electronic material producers, and yet the elimination of solder would have a profound effect on these firms as much of their SMT process expertise relates to controlling solder paste screening, placement pressure and reflow oven temperature profiles.

In other developments at such research laboratories as the Microelectronics Center of North Carolina (MCNC) or the Microelectronics Computer Consortium (MCC) in Texas, researchers are working to eliminate chip packaging altogether and create multichip modules (MCM) in which bare die or semiconductor chips are directly mounted on a substrate.[33] Consequently, it will be vital for equipment suppliers to strengthen ties with Universities and advanced research laboratories as these developments take shape for if they do not, they will once again experience the struggles of another difficult technology change.

Regulation

As mentioned above, there is significant pressure to change or eliminate the soldering process. Equipment suppliers need also to recognize the potential implications of government regulation in this area and form appropriate connections with agencies or standards committees. A paper presented at NEPCON WEST 1990 provided a useful update on the future of CFCs in electronic cleaning, focusing on the Montreal Protocol- an international treaty designed to protect the ozone layer.[34] Through excise taxes and

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[31]Emerson and Cuming Technical Data Sheet.

[32]"Conductive Epoxy Surface Mount Adhesives for Solder Replacement," Emerson and Cuming, Inc., Lexington, Massachusetts.

[33]Robert Crooker Jr., "Multichip Modules: A Business Opportunity Analysis for Micrion Corporation," Peabody Massachusetts.

[34]Stephen O. Andersen and Denise L. Manazerall, "The Future of CFCs in Electronic Cleaning," presented at NEPCON WEST, February, 1990.

other measures, the currently controlled CFCs are to be phased out by 2000. However, a rough polling of some circuit board producers has revealed that these firms are committed to eliminating CFC cleaning within two to three years! Although substitutes for these chemicals such as aqueous based solvents[35] or No-Flux style soldering[36] may have no impact on the board assembly process from the assembly equipment supplier perspective just yet, in the long run, significant process changes may be needed and this would surely disrupt the industry. Thus, some, perhaps not-so-obvious collateral linkages will become increasingly important for automated assembly equipment suppliers in the future.

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[35]"Non-CFC Cleaning Processes Explored, Surface Mount Technology, (December 1989): 10.

[36]Dr. W. Rubin, and Dr. M. Warwick, "A No-Clean Flux Review," Surface Mount Technology, (October 1990): 42.

CONCLUSION

In conclusion, I have found that the linkages manufacturing firms form with their customers must indeed change with the evolution of the product life cycle. Manufacturers that become too closely allied with their traditional customers and fail to form new linkages with new customers or the lead users of existing customers run the risk of missing important market opportunities as process and product technology naturally evolve.

This theory has been examined in the context of the automated assembly equipment business serving the printed circuit board industry. By focusing on how four firms have managed the transition of their customer's products from through-hole to surface mount packaging I have identified several ways in which suppliers need to manage customer linkages over time. Specifically, suppliers need to:

1. Develop ties with new perhaps very different customers as well as the lead users of their existing customer base.

2. Develop linkages between new personnel who possess the requisite process knowledge or advanced technology capability in the direction of major change in their industry.

3. Encourage and reward the sales force to develop broad linkages with a variety of customer personnel.

4. Forge upstream linkages with other suppliers that affect their business.

5. Encourage direct engineering interaction with key customers where possible and take full advantage of such networking opportunities as trade shows and beta site testing.

This is by no means an exhaustive list; however, the research done to date suggests that such a broader view of a firm's external relationships is essential in order to keep pace with inevitable changes in technology.

Implications

These findings have several implications for equipment suppliers in general:

Organizational Design

For whatever kind of organization that is in place, (functional, matrix) supplier firms need to be sure first that personnel across functions are encouraged to develop a broad set of external linkages and second that the firm's internal communication structure is capable of relaying critical information to the right decision makers. A broadly connected sales force that gathers significant intelligence on emerging needs is of little use if that information cannot properly be transmitted to marketing or design groups for example.

Marketing Strategy

I have argued how linkages must change in order to track the product life cycle as defined quite broadly in this paper. A key requirement then of a firm's marketing strategy is that planning groups are able to understand and act upon technical change. Here marketing and technology are intertwined- in this study for example, the emergence of SMT as complex and process intensive has had a big impact on product policy: a firm now must supply a full assembly process rather than a stand-alone machine for example, and so the marketing strategy must take this into consideration.

Employee Skill Base

Demanding that a firm must cultivate a variety of flexible external linkages also suggests that the nodes of the linkages, the sales, engineering, research, and marketing personnel be well-versed in a variety of disciplines. By encouraging training and rotational assignments, a firm can refine the eyes and ears of the organization to better receive sometimes subtle customer signals. For example, a salesman with prior service experience would be more likely to befriend the customer's maintenance foreman

because they may speak the same language. Or a marketing manager with technical training would be less hesitant about conversing with an advanced development engineer at the customer site by virtue of his own technical credibility.

Proximity to Customers

Nothing facilitates communication better than personal contact at both supplier and customer sites. Industries tend to cluster in different regions of the country and so supplier firms can improve the linkage-forming process by co-locating near important customer facilities. In such cases, however, firms must not once more become too closely allied with too few customers and so the proximity issue must be treated with caution.

Further Research

Despite several interesting results from this study, there are significant opportunities for further investigation. The specifics of the transactions between suppliers and customers deserves special attention. In particular, more work needs to be done to determine the specific content of various linkages and how firms make use of this information. How do firms assess the value of information derived from certain customers? Are firms apt to take seriously only its large and powerful customers or are smaller entrepreneurial players also valued? In addition, how much structure needs to be put into place to manage the linkage process? Can firms rely on informal mechanisms combined with management encouragement or should specific training programs be devised?

Finally, an area of particular importance is learning how to assess the timing of product life cycle dynamics. A major difficulty in the through-hole technology to surface mount technology transition has been poor forecasting. In the early 1980s it was predicted that SMT would be rapidly accepted whereas in reality, the transition has been much slower. For firms to manage their external linkages over the course of the product life cycle, they must have good information regarding the pace of change in the technology of interest.

In summary, then, supplier-customer linkages are an important consideration for technology-driven businesses. The relationships must remain fluid and successful manufacturers will be the ones who are best able to manage the evolution of these linkages over the course of the product life cycle.

BIBLIOGRAPHY

References Used

Business Periodicals Index. s.v. "Printed Circuit Boards," s.v. "Surface Mounted Technology." New York: H. W. Wilson Co.. 5 Vols. (August 1985 - July 1990).

Current Industrial Reports. s.v. "Semiconductors, PCBs and Other Electronic Components." Washington D.C.: U.S. Department of Commerce, Bureau of the Census. (1985-1988).

Predicasts Forecasts. Cleveland Ohio: Predicasts. (1990-1991).

Wards Business Directory of U.S. Private and Public Companies. New York: Gale Research, Inc., Vol. 4. 1990.

Sources Cited

Andersen, Stephen O. and Manazerall, Denise L. "The Future of CFCs in Electronic Cleaning." Presented at NEPCON WEST. (February 1990): 1593-1600.

Buckhard, Art. "Conductive Polymeric Adhesives Solve SMT Assembly Problems." Adhesives Age (October 1990): 36-39.

Clark, Kim B. "Project Scope and Product Performance: The effect of parts strategy and supplier invovlement on product development." Management Science 35 (October 1989).

Crooker, Robert M. "Multichip Modules: A Business Opportunity Analysis for Micrion Corporation." Unpublished.

Gupta, Ashok K., and Wilemon, David, "A Model for Studying R&D - Marketing Interface in the Product Innovation Process." Journal of Marketing 50 (April 1986): 7-17.

Hauser, John R., "Consumer Research to Focus on R&D Projects." Journal of Product Innovation Management (February 1984): 70-84.

Hauser, John R., and Clausing, Don, "The House of Quality." Harvard Business Review 66 (May-June 1988): 63-73.

Jackson, Barbara Bund. Winning and Keeping Industrial Customers. Lexington, Massachusetts: D.C. Heath and Co., 1985.

Krukowski, John, "Implementing SMT: a Painful Rite of Passage for Board Assemblers." Electronic Packaging and Production (October 1989).

Levitt, Theodore, "Exploit the Product Life Cycle." Harvard Business Review (November-December 1965): 81-94.

Maidique, M.A. and Zirgen, B., "A Study of Success and Failures in Product Innovations: The case of the U.S. Electronics Industry." IEEE Transactions Engineering Management (4 November 1984): 192-203.

Mangin, Charles-Henri, "Surface Mount Changes Shop Floor Economics." Electronic Packaging and Production (September 1989): 112-114.

Mohr, Jakki, "Communicating with Industrial Customers." Marketing Science Institute Conference, Melbourne, Florida Report No. 89-112. (March 8 - March 10 1989).

Newbury, Philip, "Surface Mount Assembly Machines." Electronic Packaging and Production (June 1990): 38-39.

Onkvisit, Sak, and Shaw, John. Product Life Cycles and Product Management. Westport Connecticut: Greenwood Press, Inc., 1989.

Peterson, Gary G., "Standards for Surface Mount Technology: Where We Stand." Electronics Business (March 6, 1989): 113-114.

Rubin, Dr. W., and Warwick, Dr. M., "A No-Clean Flux Review." Surface Mount Technology (October 1990): 42.

Ruekert, Robert W., and Walker, Orville C., "Marketing's Interaction with Other Functional Units: A Conceptual Framework and Empirical Evidence." Journal of Marketing 51 (January 1987): 1-19.

Schrader, Stephan. "Informal Alliances: Information Trading Between Firms." MIT Working Paper #38-91. (March 1991).

Skinner, R. N.. Launching New Products in Competitive Markets. London: The Anchor Press, Ltd., 1972.

Smith, Gordon F., and Davis, Robert T.. Marketing in Emerging Companies. Reading, Massachusetts: Addison-Wesley. 1984.

Souder, William E., "Managing Relations Between R&D and Marketing in New Product Development Projects." Journal of Product Innovation Management 5 (1988): 6-19.

Thorelli, Hans B., and Burnett, Stephen C., "The Nature of Product Life Cycles for Industrial Businesses." Journal of Marketing 45 (Fall 1981): 97-108.

Turnbull, Peter, and Valla, Jean-Paul. Strategis for International Marketing: The Management of Customer Relations in European Industrial Markets. London: Croom Helm, 1986.

Tushman, Michael L., "Managing Communication Networks in R&D Laboratories." Sloan Management Review (Winter 1979): 37-49.

Van de Ven, Andrew H., "On the Nature, Formation, and Maintenance of Relations Among Organizations." Academy of Management Review (October 4, 1976): 24-36.

Von Hippel, Eric, and Urban, Glen, "Lead User Analyses for the Development of New Industrial Products." Management Science 34 (May 1988): 569-582.

Von Hippel, Eric, "Successful Industrial Products From Customer Ideas." Journal of Marketing (January 1978): 39-49.

Zirgen, Billie Jo, and Maidique, Modesto A., "A Model of New Product Development: An Empirical Test." Management Science 36 (July 1990): 867-883.

---------- "Matching Managers to a Company's Life Cycle." Business Week (February 23, 1981): 62.

---------- "Non-CFC Cleaning Processes Explored." Surface Mount Technology (December 1989): 10.

---------- "Wanted a Manager to Fit Each Strategy." Business Week (February 25, 1980): 166.

Sources Consulted But Not Cited

Abernathy, William. The Productivity Dilemma. Baltimore: Johns Hopkins University Press, 1978.

Abernathy, William J., Clark, Kim B.. , "Innovation: Mapping the Winds of Creative Destructive. Research Policy 14 (1985): 3-22.

Basu, Dr. R.S., "Alternatives to CFCs: New Solvents for the Electronics Industry." Surface Mount Technology (December 1989): 34-37.

Coucher, Mary, and Hendrickson, Gene, "Technological Implications for SMT Board Fabrication." Electronic Packaging and Production (June 1990): 64-66.

Henderson, Rebecca M., and Clark, Kim B., "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." Administrative Science Quarterly 35 (1990): 9-30.

Keeler, R., "Buyers Warned to Beware of Mechanical Centering for SMT Assembly." Electronic Packaging and Production (August 1990): 16.

Kiechel, W., "The Decline of the Experience Curve." Fortune (October 5, 1981): 139-146.

Leibowitz, Michael R., "These Are Glory Days for SMT Production Gear Firms." Electronic Business (April 15, 1988): 74-78.

Mangin, Charles-Henri, "The Cost of SMT Assemblies." Surface Mount Technology (February 1990): 43-46.

McCreadie, John, "Contract Manufacturing Thrives on Fast SMT Growth." Electronic Business (February 19, 1990): 17.

Norton, John A., and Bass, Frank M., "A Diffusion Theory Model of Adopton and Substitution For Successive Generations of High-Technology Products." Management Science 33 September 1987): 1069-1086.

Rice, Valerie, "PCB Makers Face Rising Demand For SMT." Electronic Business (September 1, 1987): 90-96.

Schonberger, Richard J.. Building a Chain of Customers. New York: The Free Press, 1990.

Souder, William E.. Managing New Product Innovations. Lexington, Massachusetts: D.C. Heath and Co., 1987.

Stanton, Ken, "The Quiet, Innovative Evolution of Through-Hole Assembly Technology." Electronic Packaging and Production (February 1990): 102-104.

Teece, David J., "Profiting From Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." Research Policy 15 (December 1986): 285-305.

Urban, Glen, and Hauser, John. Design and Marketing of New Products. New Jersey: Prentice-Hall, Inc., 1980.

Utterback, J. M., and Hill, C. T., "The Dynamics of Product and Process Innovation." Mangement Review 69 (January 1980): 14-20.

Von Hippel, Eric, "Lead Users: A Source of Novel Product Concepts." Management Science 32 (1986): 791-805.

Von Hippel, Eric, "The Dominant Role of the User in Semiconductor and Electronic Subassembly Process Innovation." IEEE Transactions Engineering Management 24 (1977): 60-71.

Waitkus, Patricia E., SMT Aqueous Cleaning Development." Surface Mount Technology (Best of Surface Mount '90): 30-36.