ABSTRACT

Numerous contributions have been made to characterize new manufacturing practices that are expected to replace mass production. One of the concepts most frequently used in the debate is the notion of flexibility in various forms. This paper present a case study of a print circuit assembly manufacturer endeavouring a mass customization strategy, a recent manufacturing conceptualization seeking to customize products yet reaping the economies of scale successfully exploited in a mass manufacturing paradigm. The study reveal that mass customization require flexibility in terms of technology, the capabilites of the work force, organizational structure, and the relationsships between suppliers, manufacturer, and buyer firms. Notwithstanding all the thresholds a mass customizing firm has to pass, when implemented successfully, a mass customization strategy can constitute sustainable competitive advantage.

INTRODUCTION

It is acknowledged that the mass production paradigm that dominated from the end of second world war until the mid seventies have lost its strenght and is about to be superseded by a postfordist mode of production (Freeman and Perez, 1988). The decline of the mass production paradigm have been orchestrated by the global shift in manufacturing activities
outlined by Dicken (1991) and it have been suggested that the business environment have radically changed due to the emergence of new technologies, and the increasing rate of technological change and diffusion (Bettis and Hitt, 1995). There is however, still no consensus around what production paradigm that will be dominating in the future, and the debate contains a wide array of concepts that claim to comprise the nature of changing manufacturing practices. One of the latest conceptualizations suggested is the notion of mass customization (Pine, Victor, and Boynton, 1993) which refers to a flexible manufacturing process in which each customer can get a customized product manufactured through the use of flexible technology and flexible work organization. This paper provides a case study of mass customization strategies in the incircuit manufacturing industry.

In the following, we will first briefly present the ideas advanced within the postfordist debate, and present some of the most prominent ideas underlying the Japanese achievements in manufacturing. Thereafter, the methodology applied in the study is examined. The study of a printed circuit assembly manufacturer is presented and discussed and finally, conclusions and implications for practitioners as well as scholars are presented.

THE POSTFORDIST DEBATE

Since the turn of the century until the mid-seventies, a manufacturing paradigm based upon principles such as standardization of products, extensive division of labour, separation of operations and administrative work as suggested by Taylor (1903; 1911), and long production series (Kaplinsky, 1988) dominated in manufacturing. When Henry Ford integrated the use of the assembly line in his Highland Park plant, he paved the way for a continuous mass production process with consequent maximized output. To acknowledge the importance of this innovation, Antonio Gramsci (1976) rendered Ford the honour to name the entire manufacturing paradigm
that dominated in the U.S. during the interwar period as Fordism. The fordist paradigm rested upon the enormous demand for mass produced commodities such as radios, electric irons, and more sophisticated products such as automobiles, that characterized the period 1930-1970 (Clegg, 1990). In addition, the fordist paradigm was embedded in a global regulatory system developed after the second world war consisting of various agreements such as the Bretton-Woods system and free trade agreements that provided the necessary stability for the system to run smoothly (Piore and Sabel, 1984).

When the demand for traditional mass produced goods started to saturate in the late sixties, the fordist manufacturing paradigm started to loose its stability and its deficiencies became salient (Aglietta, 1979). Diminishing return on division of labour, or worse still, counterproductive effects stemming from extensive taylorization of work, in conjunction with a more differentiated demand in traditional mass production segments and protectionist tendencies in the world economy made the fordist paradigm problematic to maintain. Therefore, the notion of a post-fordist production paradigm where put on the research agenda and have spawned a number of concepts such as flexible specialization (Piore and Sabel, 1984), lean production (Womack et al, 1990), fujitsuism (Kenney and Florida, 1988), Toyotaism (Dohse et al, 1986), Japanization (Woods, 1991), neofordism (Aglietta, 1979, Boyer, 1988), and the notion of the flexible firm (Procter et al, 1994). The most noteworthy contributions in manufacturing practice after the second world war are the Japanese manufacturing methods that have attained great interest from western scholars as well as practitioners. In the first place, the interest for Japanese manufacturing methods derived from the impressive productivity achievements Japanese industry demonstrated. Today, the growth of Japanese foreign direct investments (FDI) have raised questions whether it is possible to adopt Japanese manufacturing practices in a non-Japanese context (Elger and Smith, 1994).
JAPANESE ACHIEVEMENTS

The Japanese manufacturing practices have spawned several neologisms and abbreviations, e.g. kaizen, just-in-time, TQM, quality circles (Ho, 1993). There have been some controversy whether these methods and principles are radically new approaches to manufacturing or if it is simply “old wine in new bottles”. Williams, Haslam, and Williams, (1992) question the accuracy of the dichotomy Fordism-Postfordism and claim that Henry Ford pursued “lean production” avant le lettre through the use of continuous improvements, group technology, multi-skilling and low stocks in the Highland Park plant. Moreover, several authors suggest than rather than representing a major departure from western manufacturing practices based on tayloristic principles and mass production criterias, the Japanese achievements rest upon principles developed in the West (Warner, 1994; Robinson and Schroeder, 1993). But whereas Western manufacturers tried to adopt the American mass production blue-print practices, the Japanese enabled to forge the scientific management principles into the Japanese context; “post-World War Two management reforms in Japan, such as TQM, may have been built on Taylorism rather than negating it” (Warner, 1994: 526).

Notwithstanding the origin of the Japanese manufacturing practices, the use of just-in-time “pull” production systems, TQM, and continuous improvements are manufacturing practices that has proven to be viable over time. The two key notions that comprise the objectives with the Japanese practices are (1) elimination of slack resources, i.e. attempts to reduce all buffers that is not creating any value through (i) the use of close-knit relationships between supplier and buyer (Cusumano and Takeishi, 1991), (ii) the creation of a flexible work force through the use of kaizen, job rotation and on-the-job training (Graham, 1994), and (iii) reducing work-in-progress and inventory through the use of just-in-time (Oliver and Wilkinson, 1992) and (2) flexibility and small batches in the manufacturing process in...
order to enhance the numbers of models (Womack, Jones, and Roos, 1990). The latest thrust in the field of flexible manufacturing is the notion of mass customization referring to a manufacturing process flexible enough to tailor-make products to meet customer specific demands, yet reaping the economies of scale successfully exploited by the mass production paradigm. Mass customization is thus a new manufacturing strategy aiming at creating sustainable competitive advantage.

FLEXIBILITY AND COMPETITIVE ADVANTAGE

Companies competing in the marketplace seek to create sustainable competitive advantage (Porter, 1985). The last ten years, companies’ individual resources and capabilities have been the focal point in strategy theory under the heading the resource-based view on competitive advantage (Barney, 1991; Conner, 1991; Amit and Shoemaker, 1993; Grant, 1991). The resource-based literature consider a company a bundle of capabilities, skills, and resources that are employed to provide customer with products at a lower cost or with higher value-added content than its competitors. When companies succeed in creating valuable, rare, imperfect imitable, and non-substitutable resources (Barney, 1991), these resources are employed to yield rents when competing in the marketplace (Peteraf, 1993). In this perspective on companies and competition, flexibility can be considered a resource if it is applied to create sustainable competitive advantage. Collin and Montgomery (1995) argue that numerous huge hierarchial organizations were threatened by smaller and more flexible competitors in the eighties, with a consequent major transformation of the corporate giant in the late eighties. Flexibility can thus be considered what Itami (1987) has called an invisible asset that can be used to respond faster to changing market conditions or increased uncertainty in markets (Gerwin, 1993).

The crux with the concept of flexibility is, however, as critics of the flexibility concept have pointed out, that it lacks a precise
definition and is therefore ambiguous to practitioners (Slack, 1988) as well as scholars (Hyman, 1991). The critique on the flexibility concept notwithstanding, it is applicable in terms of strategic manufacturing when taking a resource-based perspective on competitive advantage. The mass customization concept can be used to more clearly define operational flexibility used as a resource in the marketplace with a promising ability to build and maintain competitive advantage.

MASS CUSTOMIZATION: THE EDGE OF FLEXIBILITY

Slack (1990) pointed out in the the early nineties that “whereas the period of 1975 can be called the era where manufacturers discovered that quality and and cost-efficiency were not necessarily opposing objectives in the 1985-1995 could well be the era in which manufacturers draw similar conclusions about the relationships between flexibility and cost-efficiency” (Slack, 1990: 34). During the period 1985-1995, the flexibility acquired substantial attention from scholars as well as practitioners, but the forthcoming ten years the flexibility concept is likely to be differentiated further and serve as a guideline for the design of manufacturing processes. Kotler (1989) derived the notion of mass customization from the increasing segmentation of markets and acknowledge four levels of segmentation, mass markets, segmented markets, micro markets, and individual markets, that is, the “individual as a segment”. Kotler claims mass marketing is impossible due to the internal heterogeneity of even fairly standardized segments such as categories as “women at ages 18 to 34”. The very notion of a “mass market” is a fallacy in marketing theory, Kotler argues. Therefore, ”mass markets’ is dead—segmentation has now progressed to the era a mass customization” (Kotler, 1989: 47). Even though Kotler states that the individual constitute a segment in the market, it is far from clear what the “individual” refers to. Kotler examplifies with mass customization of houses and automobiles which implies that mass customization primarily deals with end-user commodities and consumer durables. Mass customization must not, however, be restricted to end-user
segments of the economy. Spira (1993) presents a mass customization program in a “lighting control” producer in the United States and Pine and Pietrocini (1993) refer to a mass customization operations in a company producing walk-in coolers, freezers, and refrigerated warehouses. Kotha (1995) reports a study of a Japanese bicycle manufacturers’ mass customization strategies and Martin (1993) presents mass customization in an insurance company. There is thus numerous sectors and segments being served by companies pursuing mass customization strategies which underline the potential and breadth of the strategy. Mass customization have been proven to be applicable in several industries and sectors of the economy.

Mass customization, can when applied successfully, constitute a sustainable competitive advantage for the individual firm (Kotha, 1995). Notwithstanding its advantages, mass customization is not, Kotha argues, the only dimension of strategic flexibility. Mass customization does require several dimensions of flexibility, resources and capabilities, and organizational design that might be inappropriate to all organizations. To Kay (1993: 15), “mass customization is a holistic concept, not one that can be applied in the narrow sense of product function and features” and suggests that mass customization is a “synthesis of a set of management innovations that have been evolving for twenty years”. Mass customization is thus an outcome of customer focus, lean production principles, continuous variety in the products, short cycle time, and finally, empowered management culture. Kay perceive mass customization as a fundamental change and a complex reintegration of the entire business and points out the need for customer orientation throughout the production process and cooperation cross-functionally. Pine et al (1993) emphasize the acknowledgement of workers’ experiences and know-how as an asset and the empowerment of employees as a important component in the mass customization strategy. A mass customization is thus a major rethinking of business practices and require flexibility in all functions. Upton (1995: 75) has pointed out that “most managers put too much faith and machines and technology, and too little faith in the day-to-day
management of people". Upton argues that what makes factories flexible is not the use of specific methods or technologies but an empowered and well trained work force. Jaikumar (1986) argues, on basis of his study of FMS installations in the U.S. and Japan that “with few exceptions, the flexible manufacturing systems installed in the United States show an astonishing lack of flexibility. In many cases, they perform worse than the conventional technology they replace. The technology itself is not to blame, it is management that makes the difference" (Jaikumar, 1986: 69, emphasis added). The differences between mass production and mass customization is presented in table 1.

<table>
<thead>
<tr>
<th>Focus</th>
<th>Mass production</th>
<th>Mass customization</th>
</tr>
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<tbody>
<tr>
<td>Goal</td>
<td>Developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them</td>
<td>Developing, producing, marketing, and delivering affordable goods and services with enough variety and customization that nearly everyone finds exactly what they want</td>
</tr>
<tr>
<td>Key Features</td>
<td>Stable demand</td>
<td>Fragmented demands</td>
</tr>
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<td></td>
<td>Large homogenous markets</td>
<td>Heterogenous niches</td>
</tr>
<tr>
<td></td>
<td>Low-cost, consistent quality, standardized goods and services</td>
<td>Low-cost, high quality, customized goods and services</td>
</tr>
<tr>
<td></td>
<td>Long product development cycles</td>
<td>Short product development time</td>
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<td></td>
<td>Long product life cycle</td>
<td>Short product life cycle</td>
</tr>
<tr>
<td>Product</td>
<td>Standardized products built to inventory</td>
<td>Standardized modules assembled based on customer needs</td>
</tr>
<tr>
<td>Structure</td>
<td>Mechanistic, bureaucratic and hierarchial</td>
<td>Organic, flexible, and relatively less hierarchal</td>
</tr>
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Table 1. Mass production versus mass customization. Source: Adapted from Kotha, (1995).
Thus, we can posit that a mass customizations strategy requires flexibility in several dimensions. We can enunciate four propositions serving as a point of departure:

1. The use of flexible technology is a prerequisite for mass customization,
2. A flexible, empowered work force supports the mass customization strategy,
3. Flexible organizational structures with fairly loosely coupled departments support the mass customization strategy, and
4. A flexible, close and committed relationship with buyer as well as suppliers is needed when endeavoring mass customization.

The second section of this paper is dealing with empirical evidence of these propositions, and a case study of a printed circuit assembly manufacturing company is presented to provide support for the mass customization theories.

METHODLOGY

Case Study Methodologies

It has been argued that scholars are free to choose the methodology that suits the problem the researcher wants to illuminate. Since all methodologies have their limits, the idea of a fixed method applicable to all kinds of problems and research areas is major fallacy in science (Feyerabend, 1975). The choice of methodology should therefore be related to the problems investigated. Yin (1994) claims that case studies are an applicable research design when the boundaries between a phenomenon and its context are not evident and the researcher wants to deliberately cover contextual conditions in order to explain, examine, or shed light on a phenomena. Eisenhardt (1989) points out that case studies typically “combine data collection methods such as archives, interviews, questionnaires,
and observations." In addition, Eisenhardt claims, theory developed from case study methodology is likely to have important strengths like "novelty, testability, and empirical validity, which arises from the intimate linkage with empirical evidence." Glaser and Strauss (1967) advocate what they refer to as grounded theory, i.e. a research strategy aiming at generating new theory through the use of qualitative research methods. The use of quantitative research methods have their strengths but risk to direct the researchers attention away from "theoretically interesting relationships that are not sufficient magnitude to be statistically significant" (Glaser and Strauss, 1967: 200). Case study methodology is therefore applicable when examining complex phenomenon with somewhat ambiguous relationships with its context. The use of case study methodology have been practiced in other studies of mass customization (Kotha, 1995).

Case study methodology require that the researcher is a good interpreter of data. Yin (1994) points out that successful case studies require that the researcher (1) is able to ask good questions and is able to interpret the answers, (2) is a good listener and not trapped by her own ideologies or preconceptions, (3) is adaptable and flexible, so that newly encountered situation can be seen as opportunities, not threats, (4) is able to grasp the issues being studied to its full extent, and (5) must be unbiased by preconceived notions, including those derived from theory. Strauss and Corbin (1990: 18) hold that the researcher undertaking qualitative research must be able to demonstrate "theoretical and social sensivity, the ability to maintain analytical distance at the same time drawing upon past experience and theoretical knowledge what is seen". Case studies thus require that the researcher have the ability to be reflexive and interpretative throughout the entire research process (Alvesson, 1995). The case study methodology is an appropriate methodology when investigating complex and multifaceted phenomena and is therefore applicable in studies of mass customization strategies.
Choice of Firm

The printed circuit assembly producer (onward referred to as PCAP) was chosen due to its fairly complex products compared to other manufacturers in the industry. PCAP pursues a differentiation strategy (Porter, 1980) and have a mix of production where approximately 50% of the total annual production are on fairly standardized products in a number of product groups, and 50% are mass customized products. Compared to Kotha’s (1995) study of a Japanese bicycle manufacturer that had achieved 10% mass customized units in terms of sales revenues, PCAP has a substantially higher rate of mass customization; approximately 50% of the total annual capacity was dedicated to mass customized products. This makes PCAP a more significant mass customization manufacturer than Kotha’s Japanese bicycle manufacturer which increase the validity of the study. It is noteworthy, however, that whereas Kotha’s study deals with a producer of end-user durables (bicycles), PCAP is manufacturing printed circuit assemblies on behalf of manufacturers of advanced products such as test equipment for CDs, gas pumps, the steering system in excavators, computer screens, diary process equipment, and so forth. The variety of end-products force PCAP to be highly flexible and adaptable to customer requirements furthermore underscore the relevance of PCAP as a mass customizing manufacturer of interest to study.

Data Collection

Data was collected in three ways: (1) interviews, (2) observations, and (3) studies of internal documents. The main data collection method was through a serie of semi-structured interviews during a period of two months. Interviews were conducted with senior executives, operation managers, sales managers, white- and blue-collar workers within PCAP. Interviews with four of the buyers of PCAP’s mass customized
products were conducted parallel to the interviews serie within PCAP. Purchasing managers, quality managers, and operations managers where representing the buyer firms. The interviews lasted between 30 minutes and four hours, with some one and a half hour as a median interview duration time. The interviews with blue-collar workers lasted in general for a shorter time than interviews with managers.

The interviews were structured around questions related to the manufacturing process, customer requirements, long term strategies, and customer relations. Throughout the interviews, somewhat provocative questions and statement were at times used to make the informants take a standpoint and to reveal their opinions in some more delicate issues. This interview strategy unraveled in some cases misconceptions and fallacies the informants were unaware of and enabled us to interprete the informants answers in a better way. Thus we obtained a better picture of the activities. The interview process was combined with observations of the manufacturing process and how the daily routines were arranged in PCAP's manufacturing process as well as at the buyer firms manufacturing function. Each interview was followed up by an analysis of how the informants answer was related to statements from other informants. Second, we were given access to move freely in the manufacturing facilities, and we made observations of the manuafacturing processes and talked more informally with employees. Finally, internal documents was studied in some cases and provided us with information on the formal procedures in by PCAP.
MASS CUSTOMIZATION AND THE PURSUIT OF COMPETITIVE ADVANTAGE

THE PRINTED CIRCUIT ASSEMBLY MANUFACTURING

The printed circuit assembly industry is an advanced manufacturing activity insofar that sophisticated knowledge and experience as well as state-of-the-art technology are employed throughout the process. Before we investigate the manufacturing process in PCAP, some concepts and definitions used within the PCA industry have to be introduced. First, *Printed circuit assembly* (PCA) refer to the finished, assembled product. The PCA, that is usually built into another product, for instance a control system, consists of basically two parts in broad terms; components and the board on which the components are assembled. Before the board is assembled, it is referred to as a *printed circuit board* (PCB). Therefore, we use the abbreviation PCB onward to underline that the product is in progress. The PCB consists of several layers which connects the components. Four layers used to be a standard PCB, but the new PCBs generation have eight layers which enable assembly of more components on the same area. The use of eight layer boards enables production of smaller PCAs which facilitates the end-user of the PCA to manufacture smaller, less space-consuming products. The PCB can be one- or two sided depending on how small the finished PCA have to be, albeit a one-sided board can be considered a standard.

Each PCB has a grid which indicate different positions where components could be assembled. When assembling the components, the CNC-machine can thus "read" the grid and assemble the components at its place named footprints. The first step in the manufacturing process, soldering paste is put on the PCB by a CNC-machine. Thereafter, the components, that can be either hole mounted or surface mounted, are assembled by a CNC-machine. Surface mounting is the newest
technology and is expected to replace the hole mounting, although the hole mounting technology is expected to remain in business for some more years. Surface mounted components are in general smaller and are more sophisticated and represent state-of-the-art technology in microelectronics. Components can be condensers, resistors, diods, ASICs (application-specific integrated circuits) etc. Some components are further categorized as fine-pitched, that is when the distance between the contacts (the connexion between the components and the PCB) on the component is small. Components with a distance less than 0.65 mm between the contacts are categorized as fine-pitched.

THE MANUFACTURING PROCESS AT PCAP

The manufacturing process at PCAP is structured around batch production (Woodward, 1965; Hill, 1991) and is based on small to medium sized batches. Small batches were between five to fifty PCBs and larger batches were up to approximately 300 units. The manufacturing process consists of two main activities; (1) the preparation, and (2) the assembly of the incircuit board. The preparation refers to the design and the layout of the board and administrative routines supporting the manufacturing process such as procurement of components. The production process starts when the buyer orders a batch of specific PCAs that is to be built into the buyers end-products. First, the layout and design of the card are prepared by CAD engineers. The buyer has three options considering the use of the CAD function within PCAP. First, the buyer can just declare what functions he wants the PCB to serve without specifying the design of the PCA. Then the CAD function and the preparation department take care of the entire manufacturing process including the CAD work. Second, the buyer can chose to send a schedule of the PCB specifying in broad terms where components should be located. In this case, the CAD function just finish the work on basis of the information the schedule provide, and make minor adjustments of the schedule. Third, the buyer can chose to make the whole CAD work in-house and
thus reduce the costs through using their own CAD function. Then the CAD operators at PCAP just undertake minor adjustments of the prior work so the PCBs can be manufactured more easily. The first and second cases were most common when the buyer was a smaller firm with limited abilities to have a CAD-function in-house and the last case was most common in bigger and more mature buyers with former experience from PBC assembly in-house. Even when the buyer made the CAD work, the CAD-function in PCAP had to make minor adjustments to make the drawings compatible with the construction database PCAP used.

After finishing the CAD work, a component engineer is examining the PCB and decides what components are feasible to use regarding buyer's requirement. Thereafter, the procurement function purchase the components. At times, especially when the end-product is used in a context with specific requirements such as medical-technical equipment or in an environment with dramatically changing temperatures, components had to be of specific quality which make PCAP dependent upon specific component manufacturers providing higher quality. Next, the manufacturing process starts with the assembly of the card in CNC-machines. The machine operator programs the machine to deal with one batch, consisting of 5 up to 300 PCBs, individually. After the components have been assembled, the PCB is visually inspected. Next, bigger and more expensive components that are hard to assemble in the CNC-machine are assembled manually. Manually assembled components and the hole mounted components are thereafter soldered through a wave soldering machine which cover the PCB with a thin surface of an alloy of tin and lead. The surface mounted components are kept in place by the solder paste which melts when the PCB pass through an oven. After completed assembly of components, the PCB are tested normally in three ways; first, the PCBs have to pass an In Circuit Test (ICT) which control that all components are functioning satisfyingly. Second, the PCBs undergo a burn-in test which lasts for five days (in the case of PCAP which consider this a quality standard). The burn-in test heats up the
PCBs to about 70° celsius and reduce the temperature back to 0° celsius to test whether the PCBs can resist drastic temperature changes. Finally, The PCBs are tested functionally to find problems the ICT failed to trace or that derive from the burn-in test. After the testing, the PCBs become PCAs, i.e. are finished products ready to be assembled into the end-product, for instance a control system, an excavator, a computer, or any product employing microelectronics. The whole manufacturing process is depicted in fig. 1.

*Figure 1. The manufacturing activities at PCAP*

Throughout the manufacturing process, PCAP has pursued customization of the product as the dominating principle for organizing work. When preparing the boards, the customer can choose size and what components should be used, and there is virtually no limitations on how the PCA can be designed. In order to achieve a manufacturing process that can handle the customization of the PCAs, various organizational and technological factors contribute to the process. All these factors have one feature as a common denominator: flexibility. Each of these factors are examined in detail in the following section. PCAP is endeavour flexibility that is contributing to the customization of the end-product in four dimensions; (1) the use of flexible technology, (2) the emphasis of the importance of a flexible, multiskilled workforce, (3) the need for a flexible organizational structure, and finally, (4) the establishment of long-term and committed relationship with buyer firms and suppliers.
FLEXIBLE TECHNOLOGY

The manufacturing process comprise the use of various flexible technology in use to mass customize the PCBs. When the buyer want to get a batch of PCAs manufactured, they send either a schedule containing information to the CAD function what functions the PCAP should be able to handle, or a CAD work finished beforehand that they want PCAP to manufacture. In the former case, PCAP’s CAD department writes the schedule and defines where the components should be assembled. In the latter case, the CAD department try to adjust the work to fit into the manufacturing process, i.e. make the product possible to manufacture in the surface assembly machine. These revisions are normally minor and aim primarily at reducing the risk for problems in the CNC machines. In both cases, the CAD department sends the finished CAD work to the supplier of PCBs in Spain or Italy through EDI. After approximately 2 weeks the supplier deliver a batch of ICs that are used in the prototype serie.

When the CAD department have finished their assignment, the preparation department make all plans and programs that the assembly group need to carry out in the manufacturing process. After the preparation department have made the planning of the manufacturing process, the CNC machine operator gather all adequate information from the construction database and the production database to program the CNC machine. Information from the CAD department, the preparation department, and information from the CNC machine are thus used as input when programming. Thereafter, The CNC machine receives all the required information from three sources which put high demand on the need for flexible technology and information technology able to disseminate real-time information from CAD department to the preparation department to the manufacturing function. Moreover, the manufacturing department serves the CAD department and preparation department with information from the CNC machine in order to
provide CAD engineers and preparation engineers with information about the assembly procedure. The use of flexible technology in combination with advanced EDI systems are thus a *sine qua non* for mass customization since it radically reduce the transaction costs (Williamson, 1975) between departments as well as between PCAP and its buyers and suppliers. Moreover, the systems have to be compatible so information can be retrieved from various systems. For instance, when the CAD department receive a schedule from a buyer where the characteristics of the PCBs are specified, it reduces the work required substantially if the CAD program can read information directly from the floppy disk and do not have to be typed manually. The information today delivered on floppy disc will in the future be sent by EDI but today, the board of PCAP believe there are security risks related to the use of EDI externally to buyers.

The use of flexible technology and information technology also reduce the switching time between programs in the CNC machine. Since information is stored in the computer system, small batches can be produced through the reduction of switching time of the CNC machine. To conclude, the use of CAD, CAM, and CAPP reduce transaction costs in the manufacturing process and helps the accumulation of experience insofar that information of all components used in the manufacturing process (approximately 14,000) are stored in the construction data base. Moreover, the use of flexible technology enable information to be shared across functions; when the CAD is finished information is disseminated to the CNC machine programmer as well as to the PCBs producer, and appropriate information is stored in the construction data base for use in the future.
FLEXIBLE WORKFORCE

PCAP pursued a flexible work force through education, on-the-job-training, job rotation and broader job assignments. Lead time was considered to be reduced if employees could handle all kinds of PCBs and the dependence on individual employees' capabilities was less problematic when trying to make employees more skilled and experienced in carrying out all assignments. In this case, PCAP had a straightforward ambition to create a flexible workforce in the same vein as the Japanese human resource management strategies (Oliver and Wilkinson, 1991). Japanese manufacturers seek to enhance flexibility through reducing the number of job classifications and actively seek to use the employees' know-how and experience. Kenney and Florida (1993:39) write "perhaps the key element of the Japanese industrial system lies in its ability to harness workers' knowledge as a source of value directly at the point of production". The mass customization strategy is reinforced by the ability of the skilled work force to handle all assembly possibilities.

The CAPP system reinforced that each blue-collar worker should be able to assemble all PCBs since employees were assigned jobs randomly insofar that neither foremen nor workers could decide what work they should do next. Therefore, employees were trained to carry out all sorts of assignments. Employees were also deliberately moved between departments for shorter periods of time, 3-4 months, in order to attain experience from other functions. Management believed this rotation between departments creates a holistic perspective on the manufacturing function among the employees. Employees from the manual assembly department were for instance trained in running the surface mounting machine and to program ASICs. This promoted organizational learning which is crucial when pursuing a mass customization strategy (Kotha, 1995). Nonaka (1994) emphasize the importance of tacit knowledge (Polanyi, 1958) in association with organizational learning.
Organizational learning, Nonaka argues, is created through a dialogue between tacit and explicit knowledge. Tacit knowledge can be transmitted between individuals through the socialization process. The conversation of explicit knowledge to tacit knowledge and vice versa is labeled internalization and externalization respectively, borrowing terms from Berger and Luckmann (1966). Explicit knowledge can be created through combinations of socialization, internalization and externalization. One of the most widely used way of making explicit knowledge obtainable is to store information in a computer systems. The modes of knowledge creation are depicted in figure 1.

![Figure 1. Modes of Knowledge Creation. Source: Adapted from Nonaka (1994) with modifications.](image)

The “prime mover” of organizational learning is, according to Nonaka (1994), the individual. But the quality of the tacit knowledge of the individual is dependent upon two factors; first, there have to be some “variety” in the individual’s experience. If the individual’s experience is limited to a few tedious operations, the tacit knowledge component tend to decrease over time and creative thinking is reduced to a minimum. Second, a factor determining the quality of the tacit knowledge is the “knowledge of experience”, that is, “knowledge through the deep personal commitment into bodily experience”. Bodily experience refers to “a reflection in which body and mind have been brought together”, i.e. physical as well as
psychological involvement when undertaking a job assignment. In short, if organizations seek to accumulate and exploit tacit as well as explicit knowledge, and create a learning organization, individual's first have to be able to rotate between different job assignment in order to promote creative thinking and problem solving and prevent the "one dimensional thinking" stemming from monotonous and repetitive tasks. Second, individual's have to be physically and mentally involved into the job assignment.

When pursuing a mass customization strategy, organizational learning and employees' involvement and participation is key factors determining the success. Therefore, job rotation and broader job assignments are crucial for a mass customization strategy. When producing PCAs, the tacit dimension of the knowledge creation is of great importance since the components and the design of the PCB is often complex and sophisticated. It is virtually impossible to "see" problems with individual PCBs when testing. Problems are rather detected and eliminated through a complex chain of reasoning based on objective test results, former experience (i.e. explicit knowledge) and tacit knowledge. For instance, after the PCBs have passed the surface mounting machine, all PCBs are visually inspected. Only a few of the employees had the ability to undertake the inspection due to its tacit content. When we asked one of the employees how she could spot problems she outright answered "I really don't know, but I still have a feeling that something is wrong and in most cases that feeling is guiding me right".

To conclude, a flexible work force seems to be a prerequisite when endeavouring a mass customization strategy. First, a flexible work force, trained to carry out a broad range of operations, nevertheless not all operations, reduce the dependence on individuals' know-how and experience which make the company less vulnerable to disturbances. Second, to enhance organizational learning and exploit human resources, which rest upon the creation of tacit and explicit knowledge and the conversation between these categories, a firm seeking to mass customize its products need to provide employees with
broader and more demanding job assignments. Thus, the flexibility of the work force, both in terms of dexterity and mental abilities, is one of the pillars in mass customization strategies.

FLEXIBLE ORGANIZATION

The mass customization strategy needs a flexible organization where departments are interacting throughout the product design and manufacturing process. The daily routines required the departments to be intertwined to a large extent. The interaction across departments was critical during the product design and development phase when information had to be disseminated between departments in real-time in order to compress the product development lead time. PCAP was thus using the “Rugby-team”-like, simultaneous product development approach suggested by Takeushi and Nonaka (1986) where different departments were cooperating and sharing information in order to reduce product development time and costs. Different departments were working in tandem and information were disseminated sideways rather than sequentially. Management supported the integration between organization and encouraged employees to work for shorter periods outside their own department to enhance their competencies and to get a broader picture of the manufacturing process. Even after the initial product development phase, departments were close-knit and were interacting to facilitate the dissemination of information through the organization.

The requirement for a flexible organizational structure in a mass customization strategy provides management with a delicate problem insofar that different department have to be fairly consolidated in order to exploit synergy effects and core competencies within departments; yet there is a need for a broad understanding for the various functions across departments and categories of employees which make the strict separation between categories of employees in different departments a suboptimal solution. In PCAP, management kept
the individual departments and stressed the need for flexibility within the informal organization. There were thus strong similarities between the organizational structure in PCAP and the notion of clans presented by Ouchi (1980). Following Williamson (1975), Ouchi argues there are two principal mechanisms for mediating transactions: markets and hierarchies. Under conditions that create market failure due to factors such as bounded rationality, opportunism, uncertainty, and so forth, transactions are undertaken within the framework of a bureaucracy in order to alleviate the impact of these market dysfunctions. The bureaucracy phenomena, first examined by Weber, rely upon a system of “hierarchical surveillance, evaluation, and direction” and thus require at least a minimum amount of stability and predictability. The problems occurs when tasks become highly unique, completely integrated, or ambiguous for other reasons and individual performance become complicated or costly to evaluate. Then, even the bureaucratic mechanisms fail. In a highly complex and hard to predict enviroment, Ouchi (1980:137) argues, “the sole form of mediation remaining is the clan, which relies upon creating goal congruence”. The clan concept emanates from Durkheim and refers to an organic association which resembles a kin network. In this context, the clan is a group of individual cooperating on basis of reciprocity, legitimate authority, and common values and beliefs, and whose mediating links are based on the clan's traditions. Clans are thus a more sophisticated organizational form than bureaucracies since clans require goal congruence and common values and that clans can handle a highly complex and ambiguous situations wherein bureaucracies have its obvious shortcomings.

The organization structure at PCAP was highly organic and information was disseminated in various directions across departments and employees were used to cooperate across functions. Thus the bureaucratic ideal type organization form cannot capture the organization structure PCAP had developed; the organization structure rested rather on the clan concept. Mass customization is a demanding strategy in terms of the need for flexibility in all dimensions. In a highly flexible
environment it is virtually impossible to evaluate all activities undertaken which underline the importance of goal congruence among employees. The goal congruence was emphasized by management through job rotation, education, on-the-job-training, and visits at the buyer firms so employees could get an understanding of how their work affected the buyer firm’s manufacturing process. For instance, the blue-collar workers visited one buyer firm, a producer of excavators. During the visit, the buyer firm representatives explained thoroughly what function the PCA had in the excavator and how crucial the quality of the PCA was to the end-user, the excavator operator. This kind of activities reinforce the employees feeling of cohesion and meaning and create an understanding among blue-collar workers of how PCAP’s products are used in the last place.

FLEXIBILITY BETWEEN FIRMS

In PCAP, flexibility between firms were considered to be a key to success when pursuing a mass customization strategy. The buyer firms were treated as departments within PCAP and both parts referred to the need for trust and commitment when building long term relationships. At several times, informants used marriage metaphors to describe the ideal relationship between supplier and buyer and both parts used a phraseology applicable to stable and committed relationships; the buyer firm representatives referred to “law and order”, “maturity” and “mutual understanding” as key characteristics of the relationship. Moreover, they expressed a preference for close spatial location to the supplier; one informant held that the supplier should be within one hour of reach and continued: “It is always so much easier to talk to someone that you have met personally, perhaps the day before.” Another informant agreed on this and pointing out: “Make business with people you met personally is more comfortable. They are just half an hour away from here so we can just get over to see them [PCAP engineers] if we have problems.” In addition, one buyer-firm representative expressed her trust for PCAP when outright putting it “it feels
like PCAP is a part of our R&D department”. Buyer firm representatives and PCAP managers thought even closer integration between firms could be beneficial for both parts. A mutual decision of what components should be used would enhance the productivity in the manufacturing process which is beneficial for both parts.

PCAP representatives on the other hand expressed similar feelings and used the same metaphors and claimed PCAP wanted partners of a certain size and turnover that promoted the “ability to build long term commitment relationships”. This “birds of a feather” worldview on business relationships pervaded the mass customization strategy and PCAP considered the buyer firms more or less as a part of the company. In the product development phase, the buyer firm and PCAP had a mutual reliance on each other's competencies and the product development process became iterative in nature. One indication of the long-term commitment and mutual trust the PCAP as well as buyer-firm representatives expressed, was that PCAP was considering to let the buyer firm get access to the component library which would enable the buyer firms to declare their preferences for components in an early stage of the product development process. Under normal business conditions, PCAP would not let an external firm get access to the component library since the access to components is one of the key success factors in the microelectronic manufacturing industry. The component library is therefore an important strategic asset.

The relationships between firms are thus consistent with the relationship marketing framework outlined by Dwyer et al (1987), Ford (1990), Morgan and Hunt, (1994), and Heide, (1994). These scholars seek to explain the relationships between firms in terms of non-discrete relationships where transaction costs are reduced through the establishment of long-term relational exchanges. Whereas in discrete exchanges, the product can be “easily evaluated, paid for with cash, and carted away” (Dwyer et al, 1987: 12), more sophisticated marketing activities require stability and mutual “trust and commitment” (Morgan and Hunt,
1994) that are provided in dyadic relationships (Ford, 1990). Though relational marketing implies switching costs and long-term commitment for all parts, it can also provide a source of competitive advantage and establish higher thresholds new market entrants have to pass (Heide, 1994). PCAP has over a longer period of time been working with the same suppliers of components and has thus invested in commitment and trust to establish stability in the supply-chain to make the production process less vulnerable to fluctuations in the component market. The same strategy are applied when creating relations with buyer-firms, which also can be seen as an attempt to enhance predictability on the demand side. In addition, Dyer (1996) showed that firms in the automobile industry, closely located to their suppliers create competitive advantage since the firms cospecialize human and physical assets. For instance, Toyota’s value chain is more specialized and more productive than GM or Nissan’s and therefore, a key factor when explaining the superior productivity seem to be the geographical proximity. Dyer thus emphasize the need for cospecialization of assets and claims that close geographical location to suppliers can provide a sustainable competitive advantage. Cusumano and Takeishi (1991) present similar findings from their study of American and Japanese automakers supplier relations. In sum, PCAP pursued long-term, dyadic relationships with suppliers as well as buyers in order to reduce transaction costs and raise entry barriers. All parts where inclined to invest heavily in commitment and trust as suggested by Morgan and Hunt (1994).

DISCUSSION

We have examined the implications for technology, job content of the employees, organizational structure, and the relationships between suppliers, manufacturer, and buyer firms (i.e. PCAP’s customers) in a mass customization strategy. When striving to enhance flexibility across all dimensions of the operations in the manufacturing process, mass customization provide companies with a strategy exploiting flexibility and
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creating competitive advantage in terms of providing customer specific designed products. The flexibility debate, which has lasted for some ten year by now, have at times failed to clearly define in what dimensions flexibility should be directed and how flexibility can be employed as a source of competitive advantage. Thus the mass customization strategy provide a nexus between flexibility and competitive advantage.

But as the case study points out, flexibility does not come neither easy nor at negligible costs. A mass customization strategy must be embedded in the organizational resources, competencies and capabilities and have to be nourished over a longer period of time. The study suggests, as emphasized by Kay (1993), that it seems problematic to pursue a piecemeal and fragmented mass customization strategy. Moreover, mass customization must emanate from a differentiation strategy (Porter, 1980) in which the company has a competitive advantage in manufacturing products with options the customer is willing to pay a higher price for. A mass customization strategy also has to be supported by the entire organization. As the case study indicat, firms cannot mass customize products by simply implementing advanced manufacturing technology if the price of the products have to be competitive. Mass customization is not just a matter of the physical assembly of the product, it is just as much a matter of informational dissemination within the company due to the fairly high information content in mass customized products (design, the customer's preferences for various options, etc) compared to standardized mass produced durables. Therefore, the technological, structural (Hill, 1991) facets of mass customization has to be supported by organizational, infrastructural factors such as wide job descriptions and assignments, flexible organizational structure, and close-knit relationships between organizations.

A mass customization strategy does however constitute competitive advantage. Following the resource-based view on strategy (cf. Collis and Montgomery, 1995), the ability to mass customize product can be considered a resource constituted by
all the interrelated competencies and capabilities the manufacturing process comprise. Reed and DeFilippi (1990) argue resources that create competitive advantage can be an outcome of causal ambiguities between competencies and activities used in the manufacturing process. Due to these causal ambiguities, competitors cannot to its full extent unravel how different components of the system support each other. Thus resources help the company to sustain its competitive advantage. Barney (1991) believes competitive advantage is constituted by resources which, inter alia, is an outcome of social complexity. Compared with the notion of causal ambiguities, social complexity is relations between resources that might be possible to unravel cognitively but still rest upon a social complexity that is hard to replicate in a new context due to individuals’ tacit knowledge, experiences, and/or personalities. The mass customization can be interpreted in terms of causal ambiguities and social complexity. Since mass customization put heavy requirements on the employees social abilities and know-how and involve numerous aspects of organizational abilities and manufacturing competencies, it is complicated to identify all facets of the strategy and implement it successfully in a new context. Moreover, pursuing a mass customization strategy built imitations barriers in terms of what Dierickx and Cool (1989) have called time compression diseconomies and asset mass efficiencies.

Dierickx and Cool claim the law of diminishing returns when input is held constant viz. time leads to time compression diseconomies. This leads to a lower output given a proportional increase in input as time is reduced. For instance, so-called “crash” R&D programs are typically less effective than programs where annual R&D outlays are lower but spread out over a proportionally longer period of time. Thus the accumulation of a stock of experiences, capabilities, and resources that is prerequisite to carry out a mass customization strategy is subject to time compression economics; it takes a considerable time to implement and run the surface mounting machines within the manufacturing process, to train and educate employees, and to establish an organic organization.
structure able to handle complex business environments, and perhaps the most time consuming factor, it takes time to establish long-term, committed, dyadic relationships with suppliers and buyers. Trust and commitment are two psychological factors subject to time compression economics; it takes considerable time to build mutual commitment and when trying to compress time and "hurry up" the process it demands costly increase in inputs. The existence of time compression economics within an industry creates considerable entry barriers.

Asset mass efficiencies is based upon the notion that “success breeds success”, i.e. historical successes translates into favourable initial stock positions which in turn shapes further asset stock accumulation. The firm’s image and reputation are typical phenomenon of asset mass efficiencies; an initial good product creates a good reputation for the company which reinforce the firm’s ability to further enhance the products’ qualities. The most important implication of the notion of asset mass efficiencies is the problems related with building asset stocks from a low initial level in an environment where competitors control a considerable stock of assets and where asset mass efficiencies is a prominent trait of the industry. There are indications that a mass customization strategy rests upon asset mass efficiencies. First, the mass customization require numerous resources which tend to reinforce eachother. When starting from nothing to build a manufacturing process able to mass customize products, the initial investment must be significant in order to attain the critical mass of resources. This requirement for investments constitute an entry barrier. Second, the importance of reputation should not be underrated. Since the micro electronic industry provide other industries with sophisticated instruments, the buyer firms cannot afford to take a chance and get a PCA that does not reach the required quality standard. One buyer firm representative expressed the importance of trust “we simply cannot afford to get defect PCAs. Then our entire product is just not working.” Thus the impact of asset mass efficiency constitute another entry barrier that protect the mass customizing firm’s competitive advantage.
A mass customization strategy thus require significant investments and time before the firm can reap the benefits. Given causal ambiguities, social complexity, time compression economics, and asset mass efficiencies, mass customization is a strategy that both exploit flexibility and creates major thresholds entering firms have to pass. The creation of sustainable competitive advantage can be illustrated in figure 3:

**Fig. 3: Mass customization and creation of sustainable competitive advantage.**

**CONCLUSIONS AND IMPLICATIONS**

According to scholars contributing to the postfordist debate, we are seeing the end of a mass production paradigm. New manufacturing practices, often developed in Japanese manufacturing companies, are continuously emerging and in most cases these practices rest upon attempts to employ inra- as well as interfirm flexibility in order to create sustainable competitive advantage. In conjenctio with the breaking up of mass markets, harnessing flexibility seem to be a a key to manufacturing success in a considerable time perspective.

This paper present an in-depth, qualitative case study of a printed circuit assembly manufacturer endeavoring a mass customization strategy. The case study suggests that mass customization of products is possible to achieve in a non-consumer durable production and that mass customization can constitute a sustainable competitive advantage due to the
complexity of the operations. More specifically, mass customization cannot, as pointed out by Kotha (1995), be restricted to the use of advanced manufacturing technologies; mass customization require an altering and rethinking of various practices within the firm as well as between firms. Foremost, managers aiming at implementing a mass customization strategy need to radically rethink the importance of the know-how and experiences of the employees since mass customization demand flexibility in all dimensions across functions within the company. Nevertheless, a successful implementation of mass customization provide companies with a possibility to exploit the notion of flexibility to its full extent. Mass customization thus provide a nexus between flexibility and competitive advantage.

The most salient implications for practitioners is the long-term commitment and belief in the mass customization strategy managers must have because the benefits of the mass customization strategy does not come neither easy, nor at low costs. Albeit the need for considerable investments, mass customization should be considered a viable manufacturing strategy with its future awaiting.
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