INTEGRATING TECHNOLOGY FOR APPAREL MASS CUSTOMIZATION

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ABSTRACT

Over time, with the change of the market expectations, the manufacturing interests have changed. The apparel industry is undergoing a shift from traditional "push" system to consumer "pull" system where consumer has the command of the product. No longer is the focus on standardized apparel products manufactured for a homogeneous market, but creating variety and customization through flexibility and quick responsiveness. This requirement to manufacture apparel products based on individual consumer needs have caused the apparel industry to undergo a fundamental shift from mass production (MP) to mass customization (MC). New technologies such as digital technology have played a major role in assisting the practice of apparel MC. However, the challenge is to identify how to effectively utilize the new technologies to accomplish the goal of apparel MC.

The existing apparel MC systems, extent and points of customization are critically reviewed. The new technologies and their evolution are investigated. An apparel industry survey, case studies and industry expert interviews were conducted to identify the existing industry practice of apparel MC, the technology usage and importance of integration of technologies to the MC apparel manufacturing process.

MC of apparel has not yet reached a critical mass in the apparel industry. There are very few benchmark companies who practice this strategy efficiently. Other MP companies who attempted this have only experimented but have not extended the principles to their entire line of apparel products. However, based on the survey results, it is apparent that companies have potential to accomplish the goals demanded by MC using new technologies. Also, it is apparent that companies are seeking to use new digital technologies to transfer information in addition to management strategies such as partnerships with courier companies to cut down the lead time to supply the customized product to the customer more efficiently.

1.0 MASS-CUSTOMIZATION

1.1 Introduction

A customized apparel product can be identified in two broad areas. "Occupational-Customized" apparel such as a product with the monogram on it, sports uniforms with the name and number on it, or uniforms for service, career and occupation, have existed in market place for long time. "Consumer-Customized" apparel such as products that can be made to customer's fit, specifications, design (print) or combination of these are becoming popular and the demand for these products continues to grow. Therefore, MC is an emerging apparel business practice.

1.2 Definition and Insights

The term “mass-customization” (MC) was first introduced by Stan Davis in the book ‘future perfect’ in 1987 (Davis, 1996). As Pine (1993) describes, a new paradigm of MC evolved in 1960’s and emerged into management consciousness in the 1980’s. To cater for the market turbulences characterized by unstable and unpredictable demand levels, heterogeneous desires, price, quality and style consciousness, high level of buyer power, competitive intensity, product differentiation and saturation, the manufacturing focus was turned from MP to the new system of MC. As Kamali and Locker (2002) describes, “the goal of MC is to develop, produce, market and deliver products with enough variety so that every consumer finds exactly what he/she wants when he/she wants it”. As Silveira, Borenstein & Fogliatto (2001) explain, MC has a broader and a narrower approach. The broad concept defines MC as the ability to provide individually designed products to every customer through high process agility, flexibility and integration whereas the narrowly defined more practical concept discusses MC as a system that uses information technology, flexible processes, and organizational structures to deliver a wide range of products that meet specific needs of individual customers, at a cost near that of MP items. With regard to apparel, a process of MC named “co-design” allows a customer to choose an individualized combination of product style, fabric, color and size from a group of options. Mass customization has been identified as one of the top ten emerging technologies by the George Washington University forecast report (Halal, 2002). Staples (2001) discusses MC as an out growth of MP which is a “consumer driven business strategy that uses information and manufacturing technology to efficiently produce goods with maximum differentiation and low-cost production, and characterized by “individualized mass production”. According to Pine (1999), MC is the use of mass production techniques to quickly assemble goods and services that are uniquely tailored to the demands of individual customers at prices comparable to mass produced goods. He further explains that to be effective, MC manufacturing must combine the cost saving efficiencies of MP with the value added process associated with customizing. Pine II (1999) explains that this new concept of MC as a dynamic system feedback loop as shown in the Figure 1, that is the reverse of the model explained under the heading of Mass Production.

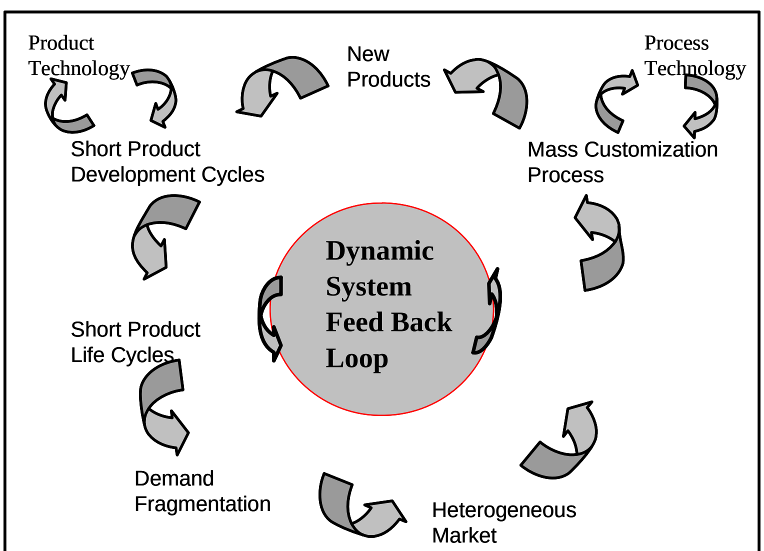

Figure 1: The new paradigm of MC as a dynamic system feedback loop (Pine-II, 1999)

Unstable demand for individual products has caused fragmented markets which demand for different flavors of similar products. Due to this reason, large homogeneous markets have become heterogeneous. The logic of MP which was discussed as "lower prices resulted in greater sales, greater sales in higher volumes, higher volumes in lower costs, and lower costs looped back around to allow even lower prices and so on" (Pine-II, 1999) now need to be modified and applied to the process of MC to be able to get the cost advantages of MP for customized products. Lee and Chen (1999) graphically represented the concept of MC defined by Pine as shown in the Figure 2. They discuss technologies such as 'smart card', 'body scanning', and information collection and transfer as examples in apparel industry.

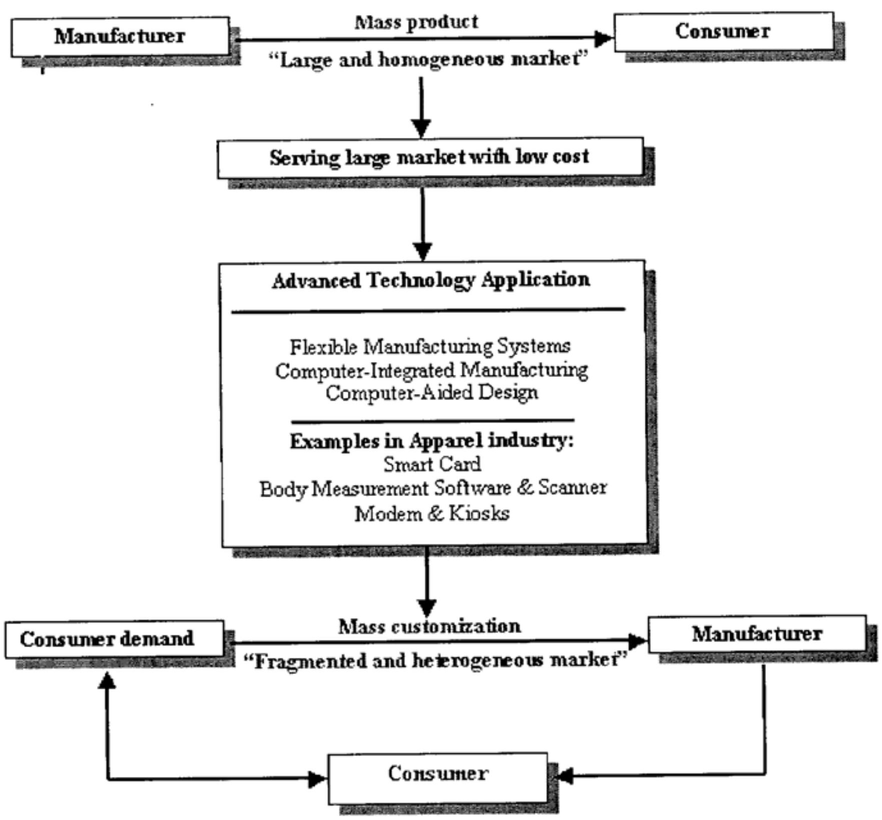

Figure 2: Concept of mass customization (Lee & Chen, 1999)

To achieve MC the following tasks need to be accomplished (Gardner, 2003). However, it is required to analyze these tasks with the apparel manufacturing point of view which is the challenge for the apparel industry.

- Proactively developing families of products around modular product architecture
- Implementing flow manufacturing to achieve batch size of one capability
- Establishing a spontaneous supply chain around standard materials

- Creating agile order entry systems based on configurators
- Building parametric CAD templates with automatic CAD/CAM links to CNC equipment.

As per Anderson (2003), the strategy to implement mass-customization is

- Supply chain and operational simplification
- Development of a spontaneous supply chain, concurrent design of versatile products
- On-demand lean production and the mass-customization of variety

Also, he explains that the cost can be lesser than the mass-produced batches if the cost is calculated accurately on a total cost basis.

According to Anderson (2003), MC is the quick and efficient approach to product customization. Furthermore, it is the ability to quickly and efficiently build-to-order customized products, which can be customized for individual customers, or niche markets such as specific countries or regions. Electronic business and MC have created new expectations in the marketplace and new demands for manufacturers. Manufacturers of configurable products must rapidly transition to a MC business strategy and, as a consequence, become lean, agile, and Internet-accessible (Gardner, 2003). Another way of addressing MC is manufacturing custom products quickly and efficiently in quantities as low as one and assembling ready-to-made modules for customer demand (Anderson, 2003). To achieve MC, Anderson (2003) suggests that supply chains need to be simplified by product line rationalization, part standardization, material variety reduction and selective vertical integration. However, it has not been discussed clearly how modularization and part standardization can be used for manufacturing custom products for individual customers or for market segments. Duray et. al. (2000) argue that customer involvement and modularity are the key elements in defining MC even though other characteristics such as flexibility and agility are important in operations perspective. The basic nature of customization and the means for achieving customization at or near MP costs are considered as the boundaries. The practice of mass customization is argued in various ways. For example, it is argued that a customized product is designed specifically to meet the needs of a specific customer and not the variety offered to the market place. The variety offered to the market place may substitute MC by satisfying customers and some authors and industry experts may argue that producing for the variety is MC (Duray et al., 2000). Looking at the practical aspect, Anderson (2004) viewed MC as an approach that uses information technology, flexible processes and organizational structures to deliver a wide range of apparel products that meet individual customer needs at a cost near that of a mass produced products (Anderson, 2004). However, the authors believe that apparel MC is manufacturing apparel for individual customer demand and personalizing it for the preference of the customer. To achieve this task it is imperative that companies integrate the advanced technologies to increase the flexibility and speed up the supply chain.

2. 0 TECHNOLOGY ENABLING APPAREL MASS-CUSTOMIZATION

To offer a high level of variety in the apparel products requires a high level of variation in the production. This requirement may not be attainable through specialized MP techniques alone. Flexibility in manufacturing will become the major need which is as Pine II (1999) explained as “antithesis of Mass Production”. Application of product technologies that provide better product configurations and greater adaptability supports product variety and shorter product development cycle time. The required system must be driven by markets and customers, and must produce number of high quality products through short production runs with short changeover times and with low work-in-process. Flexible manufacturing and computer integrated manufacturing are examples of process technologies which help towards making the production process capable of producing variety. Experts view the processes as even more important than products and the technology that assist in enabling processes for MC. As customers demand customized products, a greater need arises to re-engineer processes for MC. The production system may need to be equipped with latest MC enabling technologies in addition to general purpose machinery and a high skilled work force. In MP, products are first developed followed by creating processes to manufacture products by relating the product to the process whereas in MC the processes are generally created first and remain decoupled from the variety of flow of products (Pine-II, 1999). A premium price for the customized products can be charged which can overcome the losses due to product variation in manufacturing compared to MP.

According to Zipkin (2001), elicitation (a mechanism for marketers to interact with customers to obtain specific needs), process flexibility and logistics are the three main components which need to be considered in implementing a successful MC practice. It is also very important that these components are properly integrated to effectively coordinate between order management, manufacturing and distribution. “System choice boards” enable a company to offer the customer a menu of attributes, components, prices, and delivery options in designing a product. Design technologies such as Computer Aided Design (CAD), virtual reality and multimedia technology enable the customer to design their preference, then integrate the customers’ selection with the firms procument, assembly and delivery system. These provide a better grasp of customer requirement in elicitation (Berman, 2002). Firms not using Web-based elicitation in MC must be careful not to have a margin of error in interpreting the customer idea as the order replacement in case of an error become very expensive. A flexible production system, with the main goal of rapidly producing customized goods at a cost comparable to the mass produced one, has become a major challenge.

A technologically sound information system is required which can analyze the complete supply chain from individual customer order arrival to the logistics to deliver the product. Checking the credit rating of the customer, developing a list of product requirement with suppliers to fulfill the order, determining manufacturing specification based on order configuration, setting up flexible manufacturing system, arranging for shipment of finished product and enabling order status retrieval are some of the major activities in the process chain that needs to be addressed through sound technologies. An upstream link between the manufacturer and the suppliers is inevitable. Barcode and barcode scanning technology enable a firm to track the product through the chain. According to Alexander (1999),

> “manufacturers will need electronic order-acquisition systems that capture people’s measurements over the Web or in retail stores; order-processing software to coordinate the acquisition of raw materials and the shipment of

> finished goods; database to make sure custom clothing is designed to the right specifications; and computer aided design system that can convert customer designs into cut pieces of cloth that can be sewn together”(54) (Alexandar, 1999).

Compared to MP, MC requires re-engineering of all the processes of a supply chain network and each participating organization to support a demand driven engine. One-to-one marketing, modularly designed product structures and standardized processes are important aspects of a mass-customized manufacturing which needs to be backed by sound technologies (Green, 1999).

New technologies such as non-contact body measurements, digital printing, CAD, virtual technologies, information technology systems, and network technologies are more advanced than the current flexible manufacturing systems (FMS). FMS need to be re-tooled to accommodate MC product data and the full integration of customized production in MP. MC is expected as an economically sound alternative to MP with regard to apparel.

3.0 TECHNOLOGY DRIVEN APPAREL MASS-CUSTOMIZATION PRACTICES

Burns and Bryant (1997) explained that MC in apparel is processed by computer technology and these processes employ four steps. These are; obtain customer measurements by a sales person with the assistance of a computer, enter the data into a computer and alter specifications as preferred by customer, sending adjusted measurements to a fabric cutting machine to obtain customized garment pieces with barcode labels, assembled, and retailed (Burns & Bryant, 1997).

As Textile & Clothing Technology Corporation [TC] [2] discusses, MC for apparel and footwear can be positioned into three main categories, personalization, fit and design. For personalization, products are customized and produced in bulk for consumer requests. The dimensions of the product in relation to the body and/or the way the product fit the body is explained as the fit. The personalized body measurements and specifications are supplied to the manufacturing process to be individually made to meet the customer requirements. The highest level of customization can be achieved when the customer decides on the design of the product which is, in most situations, carried out electronically. Also, the customer may be given a finite but large option to select in the form of a menu, e.g. color, fabric, construction, accessories, thread, etc. The designer can access the selections and design the product as per customer’s request (Textile-Clothing-Technology-Corporation, n.d.).

The Clemson Apparel Research (CAR) military dress shirt MC model discusses the input of individual measurements through a CAR developed order model and finalize the pattern and marker through a database search and CAD design system before they are sent for manufacturing (Chenemilla, 2001). The Apparel Research Network (ARN) apparel order processing module (AOPM) project was carried out to develop a system to retrieve and process special measurement orders and stock orders for military clothing. The CAR initiated the electronic order form (EOF) to place the special measurements ordering process on a website replacing the AOPM’s special measurement communication functionality. Military locations which require these special measurement clothes request their orders online and these information will be accessed by defense apparel manufacturers to be used in initiating the manufacturing process (Carley, 1999). Nilsson (1993) was one of the earliest researchers who identified networking approach with the concept of Fully Integrated Garment Manufacturing Architecture (FIGARMA), later developed a model named “project inter-link” to shorten the apparel pipeline which is important in MC of apparel.

Based on consumer research, Anderson et al. (1998) indicates that in the process of mass-customized manufacturing, digital information and new technology would help in developing customized apparel with four approaches. These are “expanded selection or search” to access various manufacturers product lines, “design option” to select the design from options given by the manufacturer, “co-design” to obtain additional personal fit, and “total custom” to communicate customer’s design to manufacturer. Research has been carried out to identify consumer wants, needs and interests to be combined with mass production strategy, with flexible manufacturing and information technology to meet consumer demands with customized textile and apparel products. A model that represents the underlying notion that MC grows out of advanced MP process methodology is discussed by Anderson et al. (1998). This MC consumer driven model is determined by meshing the standardized capabilities of the MP process with enabling technologies that allow for individualizing standardized components. Consumer request for ‘cloth-clones’ which is multiple versions of currently existing successful styles, total custom garments and co-design which is selecting from a menu of standardized products are discussed (Anderson, Brannon, Ulrich, Marshall, & staples, 1998).

A research project to measure the interest of female consumers in levels and options for MC of apparel has been carried out with a national sample of more than 1000 females of ages 18-76. About 40% have shown the interest in designing their own clothing, 40.9% have indicated a high interest in online access, 37.8% have shown interest in using an Interactive Personal Advisor, and over 41% have shown interest in using the Smart Card. Questions about the online service access has been offered with technology services such as Interactive Personal Advisor, Smart Card, and participating in Customized Design (Biedron & Anderson, n. d.). Further, process in MC is considered as the involvement of customer in design, production or delivery before the actual sales transaction, using technology to limit the cost. Internet has become a good communication medium to capture customer requirements. Results of a research carried out suggests that high consumer satisfaction can be achieved with design involvement in a web-based mass customization process (Kamali & Loker, 2002).

In consideration of information technology, Piller (n.d.) developed a model with an integrated information flow (Figure 3), which can be used to direct managers, implementing or supervising a MC concept.

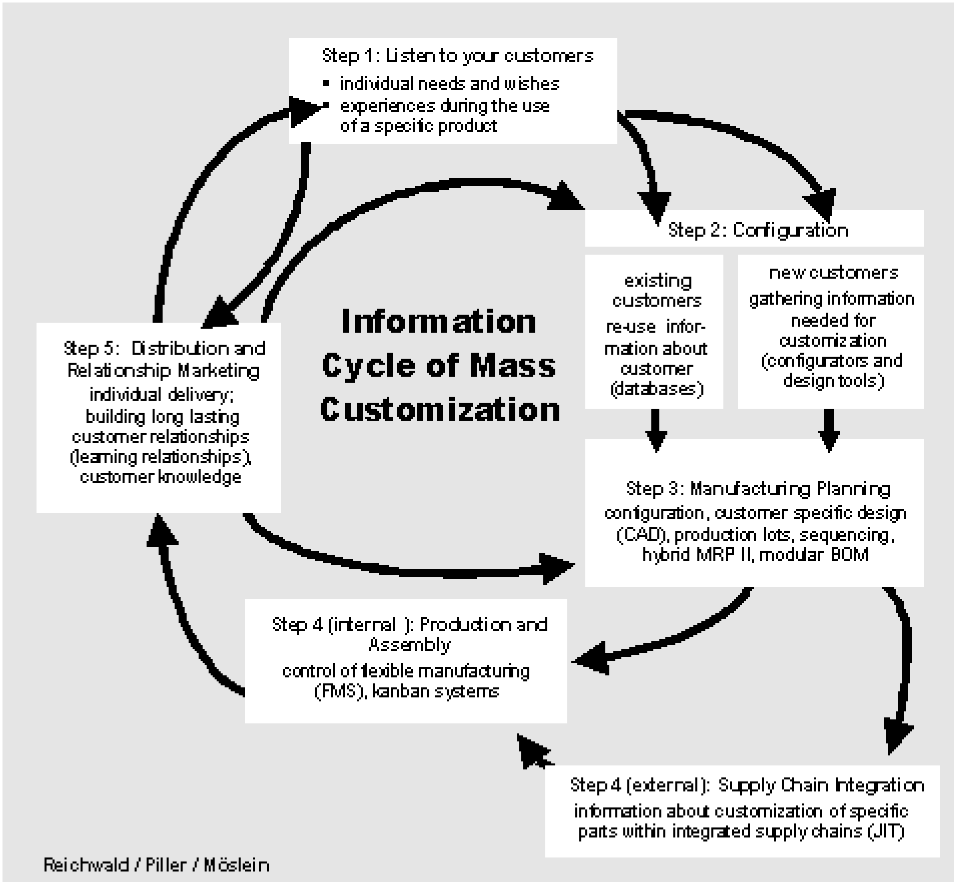

Figure 3: The information cycle of MC (Piller, n.d.)

The cycle starts with the individual needs of each customer. The center of each mass customization program has to have information about the desires of a customer group regarding the product. In the configuration stage, the task is to transfer the customers' ideas into clear product specifications. This is one of the most critical parts of any mass customization business. After an order is placed, it is transferred into specific manufacturing tasks with scheduling activities, and the production tasks are transferred to the responsible process units, whereby suppliers may be integrated in the customization of some parts. To this point the process is on information level and in production and supply chain integration stage manufacturing activities will start. The result may be an extension of the economically possible degree of individualization, a speeding up of the processes, and cost savings due to specialization and faster learning effects. After the product is distributed, the relationship building needs to be continued that started with the configuration process. Addition to this information cycle concerning apparel can be the information at the beginning of the cycle offered to the consumer (to select from options) based on the manufacturability of the mass-customized manufacturing system.

When the digital printing technology is considered, a MC functional model for digitally printed garments is discussed by Chenemilla (2001) as shown in the Figure 4. This model is expressed in three sections, namely Decision, Order and Execution. The model allows for different levels of customization and includes the lowest level which may be garment alteration, logo, fabric color and type to the highest level which indicates the garment style and textile design. Once the decision is made with new or existing materials, specifications, and measurements, the order is transmitted to the manufacturing facility in which the fabric printing, or customized fabric design creation and digital printing are taken place. With the computer assisted pattern design system the patterns for the customized style are produced. After post treating the digitally printed fabric, it will be cut sewn and finished accordingly.

4.0 ANALYSIS OF EXISTING AND NEW TECHNOLOGIES THAT ASSIST APPAREL MASS CUSTOMIZATION

Based on a detailed research study by the author (Senanayake, 2004), a summary of apparel assembly and supporting technology infrastructure in the apparel industry is graphically represented as shown in Figure 5. The existing apparel manufacturing systems, system parameters, assembly technologies, their developments and other strategies to achieve various needs were analyzed. The research covered the various forces at work such as automation to lower cost, motor and electronic technology for flexibility and control, forward and backward integration, new technologies, etc. to achieve apparel manufacturing system expectations. It was found that the development of various technologies for apparel production were mainly aimed at areas such as automation and mechanization, which in turn lead to combining/linking and deskilling operations, and improved material handling to support system needs such as improved productivity, quality, cost and fast response. Also, it was apparent that the development of technologies such as motor technology, electronics and digital technology and other supporting technologies have made a major impact on the development of apparel assembly technologies in achieving system needs specially for the MP of apparel. The assembly technology continuous to be refined with new technology developments emerging at a considerable rate which includes both sewing and supporting technologies (see Figure 6). The dynamic nature of this continuous development in mechanical, electrical, electronic, digital and information technology related to assembly technology provides evidence that sewing technology is still in the middle of a revolution related to apparel manufacturing, and the apparel production world is in a stage of continuous development. These available main technologies and supporting technologies are capable of providing assistance in achieving effective apparel manufacturing for MC.

The manufacturing or assembly systems continue to evolve to suit the demand variety of the customers such as mass customization practice. Also, there will be a product variety from basics to haute couture. In addition to assembly technology, other supporting technologies have evolved over time to fulfill technology needs that can overcome difficulties in manufacturing product variety. These technologies are discussed and expect to be forerunners in the mass-customized apparel manufacturing.

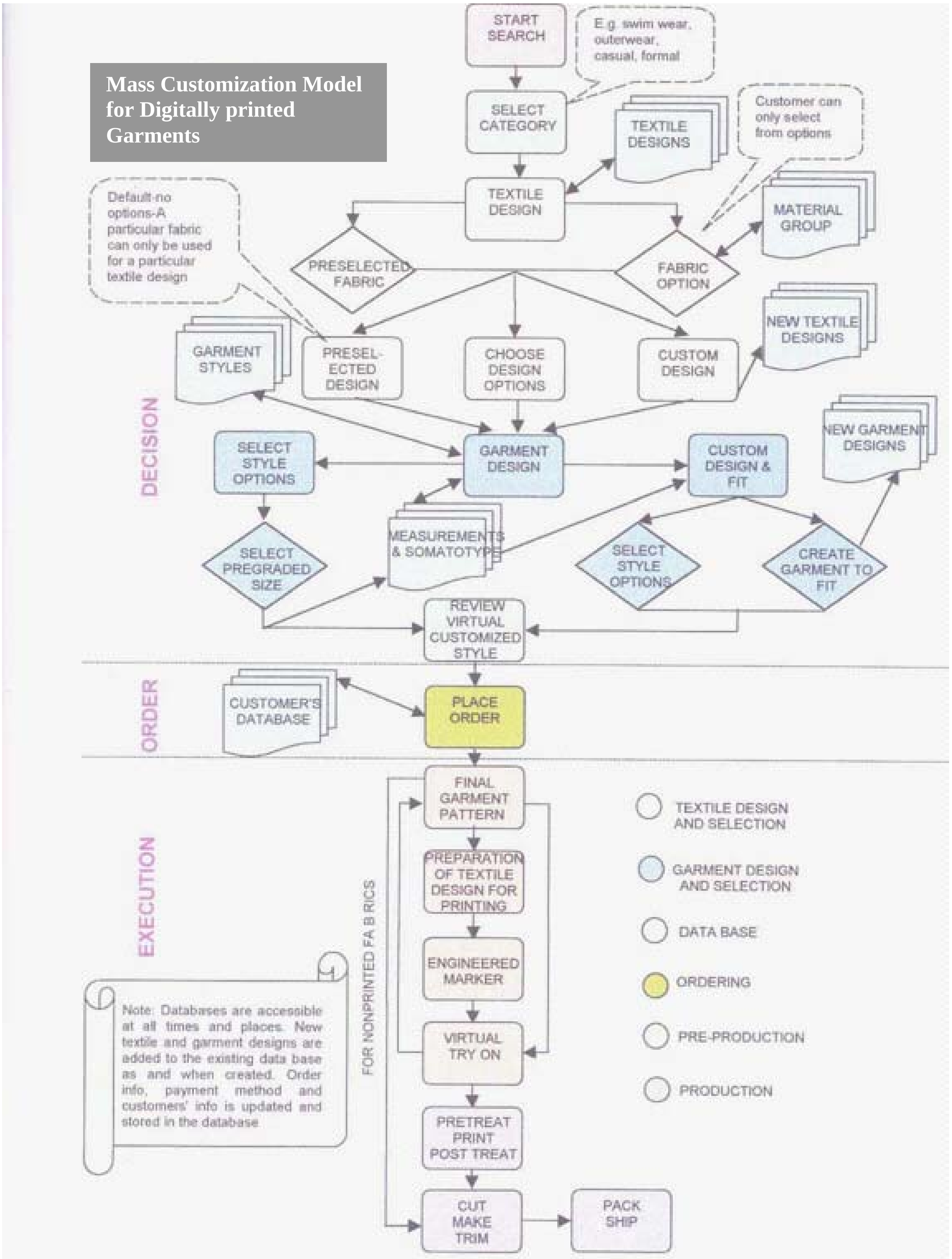

Figure 4: MC model for digitally printed garments (Chenemilla, 2001)

To understand how sewing technology and other supporting technologies have evolved over time, the number of patents issued for these technologies were analyzed. The U.S. Patents database was searched in the Title field using Legends shown on the graph below (Figure 6) and the average number of patents issued for each year since 1971 up to 2002 are graphically represented in Figure 6.

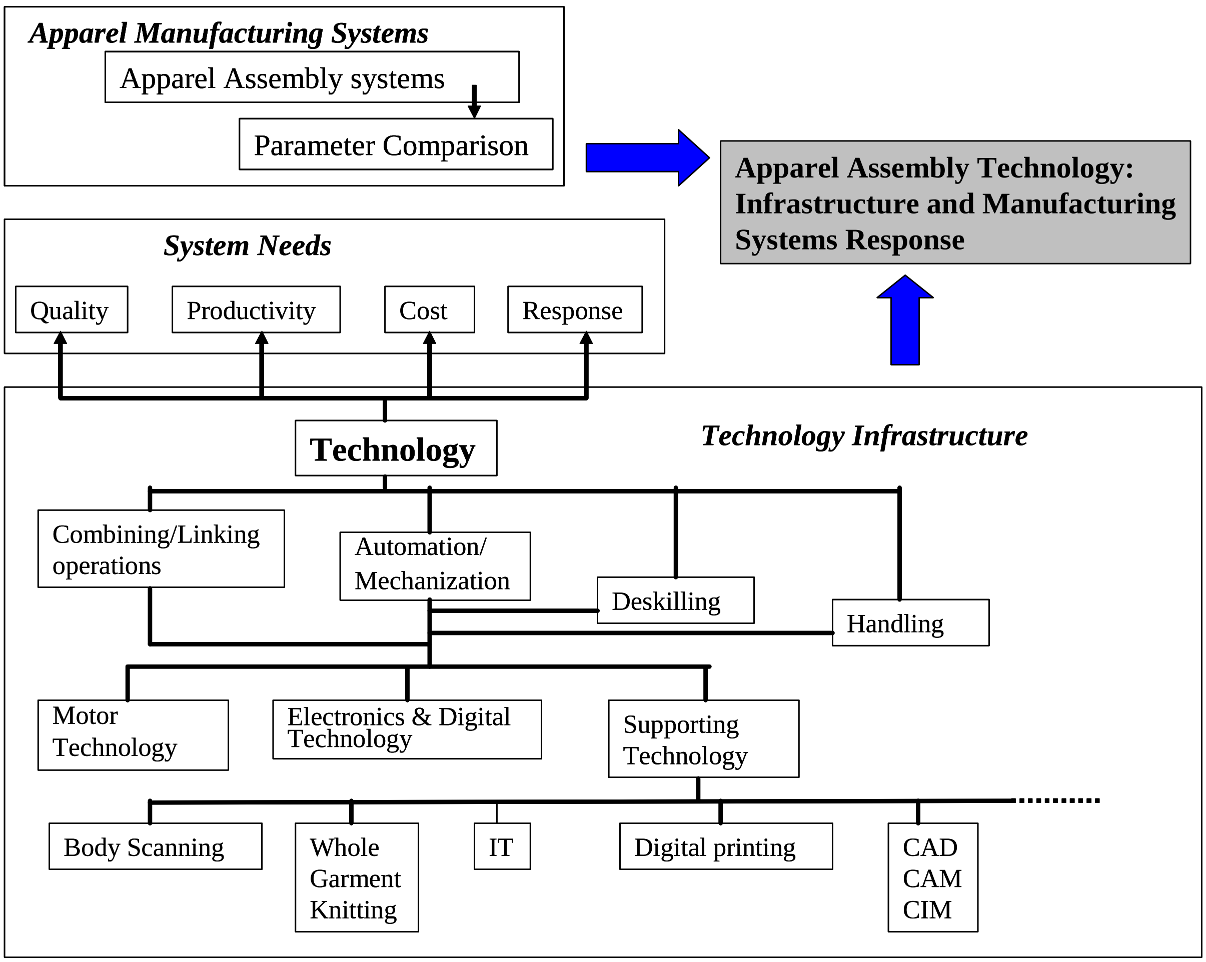

Figure 5: Understanding apparel assembly technology, infrastructure and system response (Senanayake, 2004)

The number of patents related to sewing has averaged over 100 per year over the last three decades. During the first two decades, the average patents per year related to sewing is higher due to the fact that it was a period of high concentration in mechanization and automation. Even though there are not many visible technology developments with regard to sewing machines after the Tice electronic sewing machine developed in 1994 (Hasty, 1994), there are many other patents issued related to the sewing technology. The technologies such as CAD, digital printing, body scanning and whole garment knitting were developed rapidly in 1990's. By observing the above overall patents landscape, it is apparent that sewing patents still remains about 100 per year whereas the total supporting technology patents amounts to about 75% of the sewing patents.

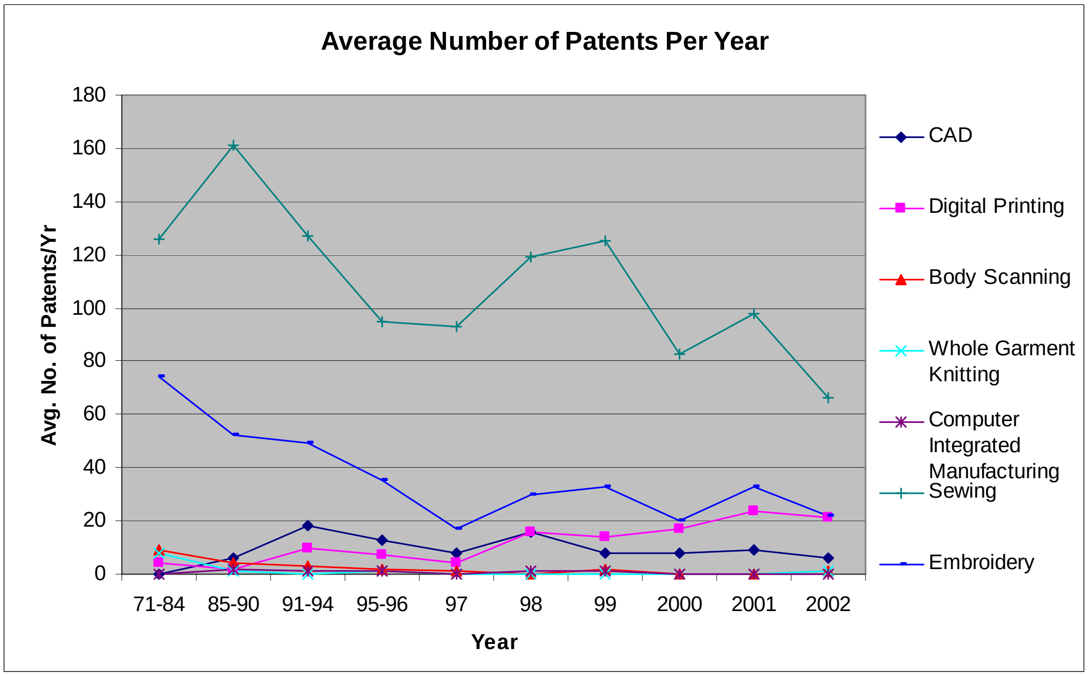

Figure 6: Sewing and supporting technology patents issued per year (U.S.Patents, n. d.)

Digital printing of textiles is currently in the very early stages of its life cycle but it is assumed that printing on textiles using this technology will become a significant force in the MC apparel manufacturing. Digital printing to produce images, designs or logos on finished garments is already being carried out by several companies. This technology offers the possibility of short runs, flexible apparel manufacturing, personalization and rapid response which are inevitable in apparel MC. Further, it can be used by the apparel manufacturer in direct digital printing supply chains or can be used by the textile manufacturers in alternative supply chains to print on textile materials (Fralix, 2000). In other words, sewn product manufacturers will assume responsibility for fabric coloration and may deliver the end product to the customer in batches of one. Also, according to Watkins (1997), one way of satisfying the demand of the retailers would be to move dyeing and finishing process downstream to apparel manufacturers (Watkins, 1997). Toward this end, researchers are involved in the integration of digital printing into the agile manufacturing environment for MC. Automation of design strategies for the engineering of a continuous print design that matches as it crosses darts, side seams, shoulder seams, armholes, collars and lapels is in research process (Tait, 1999). Some of the companies who participated in the survey conducted as a part of this research, use digital printing as the way of customizing prints and designs on sewn products.

The current version of embroidery technology is another popular technology that is considered in mass customization which consists of electronically programmable multi-head automatic profile stitching machines. This large area programmable pattern sewing is explained as, electronic, single needle, cylinder or flat bed, lockstitch pattern sewing (AAMA, 1992). This technology includes programmable, complicated pattern stitching with seams, which are straight, arcs and zigzags to make complex patterns. The number of heads, thread colors, machine speeds, stitches per design and the design area that a machine can hold is ever increasing. Also, the technology has come a long way to change the way that patterns were stored on punched tapes to other storage devices such as floppy drives, hard drives, zip drives and compact disks which can be communicated easily. The easy communication is one of the important aspects in mass-customized apparel manufacturing that require minimum time to transfer product information. Free software is now available for the embroidery industry which can be downloaded through the Internet to view embroidery design files and manipulate them as needed to modify and then to exchange the files between machines, e.g. the Embroidery Design Viewer from Coats (Anon., 2002). Multi-level work holders with rotating arms, optional integration devices for sequin, cord/loop and double roller cord, etc., bobbin changes, stop motions, design placements and thread cutters allow complex fabric joining in large area pattern sewing. The embroidery process can take place within the apparel manufacturing unit or at a separate location such as the distribution center, finishing department, etc. based on the mass-customized manufacturing interest and technical constraints.

Flexible manufacturing for MC requires flexible information technology. The developments in information technology has provided the ability of MC being adopted as an acceptable business model (Istook, 2002). Not all environments require the same level of information. In general, the information technology used in the assembly floor should be able to support, locate and maintain good inventory flow in a Progressive Bundle Unit compared to movement of product through many operations in a short time period in a Unit Production System. With mass-customized manufacturing it is now required to track single units rather then batches. It could be seen that more manufacturing organizations deal with information regarding the product than dealing with the product itself. This implies that there will be more information produced than before and the information needs to be meaningful to aid the MC apparel manufacturing process. Moving from bundle systems to flexible mass-customized manufacturing systems demand that information technology be developed rapidly to cater for the characteristics of the flexible systems. During the past few decades there have been many advances in information technology such as the inexpensive, yet powerful microcomputer and the ability to connect these computers to a wide variety of other computers in networks. The literature suggests that the old batch oriented computer systems to handle customer orders need to be replaced with the advanced CIM factory control systems that would broadcast the order requirements to every automated station on the production line based on the bar code of the unit at that station. Each station will be informed what unique operation that needs to be performed at the station (Eastwood, 1996). As Silveira et al. (2001) discusses, MC enabling technologies that support the implementation are advanced manufacturing technologies (AMT) such as computer numerical control (CNC) and FMS, and communication and network technologies such as CAD, CAM, CIM and electronic data interchange (EDI) (Silveira, Borenstein, & Fogliatto, 2001).

MC manufacturing requires a new generation of shopfloor control systems that can dynamically respond to customer orders and unanticipated changes in the production environment. Requirements in this regard include reconfigurability, decomposability, and scalability to achieve make-to-order with a short response time. Efforts have been made to design control systems for some industries by leveraging recent progresses in computing and communication technology including new software engineering methods and control technologies such as smart sensors and actuators, open architectures and fast reliable networks (Tseng & Piller, 2003).

The enterprise resource planning (ERP) systems, which are suites of computer programs that facilitate the organization of information, can be used by employees at all levels of the manufacturing organization (AAMA, 1990). With the development of standards to communicate between manufacturing teams, the computer programs are developed to run on a wide variety of computers with little or no modification. A large amount of literature is available in relation to information technology for apparel assembly systems. The author also discusses this area in the paper "measures for new product development" (Senanayake & Little, 2001). The evolution of the Internet has provided the means for sharing technical/product information among all groups involved from product development to merchandising and retail. With a universal, low-cost, high-performance network it has transformed how companies conduct every aspect of their businesses. While the Internet has been in existence for more than 30 years, its use for apparel industry has grown exponentially since the early 1990s (Fralix, 2000). The most significant change is in the way retailers, apparel companies and textile suppliers share information using the Internet as the backbone medium. One such example is the "TUKAweb" offered by Tukatech Inc.(TUKAweb, n.d.). Furthermore, the world-wide-web has brought the customer closer to the mass-customized apparel manufacturer to negotiate the customization requirement which is called "elicitation".

The CAD technology related to apparel is one that which has been successfully developed such that the technology is capable of handling most of the pre-production and part of the production functions in mass production of apparel using complex computer software and hardware. Most of these developments of CAD have been comparatively well discussed in the literature. CAD technology for mass-customized apparel manufacturing is being researched and according to Istook (2002), "a significant amount of 'behind the scenes' effort is still required in order to provide the color selection and fit of each garment that might be requested by individual customers". CAD systems with faster pattern making abilities and automatic pattern alteration methods provide the Fit Customization (Senanayake, 2004; Little, & Senanayake, 2004) for apparel MC. Also, as it is important to customize fit of proven styles without additional input from designers or pattern makers quickly, companies with large libraries of patterns with garment styles will be able to implement MC using the CAD technologies with automatic pattern alteration systems.

With the integration of computer controls into handling, e.g. UPS, integration of technologies such as barcodes and barcode readers for realtime production control, and development of communication technology have enhanced the effort for computer integrated apparel manufacturing.

Advancement of textile automation, especially in knitting, has transformed the traditional spread-cut-sew process of apparel manufacturing in to an automated knitting process by allowing to "shape" and "link" knitted fabric panels into garments. Computer integration coupled with advanced knitting concepts has almost automated the entire process of making knit garments (Shima-Seiki, n.d.). One of the major benefits of this technology is that it has the ability to produce one garment of a particular design with different colors with easy manipulation of the programs. This process is really significant because, at the time of writing this paper a complete garment manufacturing system has not developed with woven fabrics. And this technology can be very important in apparel MC that can even achieve higher end Design Customization (Senanayake, 2004; Little, & Senanayake, 2004).

Among the recent technological advances, there is a growing interest of capturing human body measurement using the scanning technology. An accurate data set of the surface of the body is needed in order to develop consistent body measurements and thus accurate patterns. There is a very high expectation for this technology to drive towards Fit Customization (Senanayake, 2004; Little, & Senanayake, 2004). The made-to-measure apparel requires underlying technology to facilitate acquiring human body measurements and extracting appropriate critical measurements so that patterns can be altered for the customer. A nationwide size survey was completed in 2003 to obtain human body measurements of the USA population using the body scanning technology to develop size standards called "Size USA" (Size-USA, n.d.). Research is being carried out to open up the 3-D scanned body image to produce 2-D patterns which will help the apparel MC to a greater extent.

5.0 SURVEY OF MASS CUSTOMIZATION PRACTICES

The results of a survey of Mass-customization practices will be presented to illustrate the current practices in mass-customization of apparel. In addition to the research findings, the presentation will focus on the company profiles that practice Mass-customized apparel manufacturing, MC apparel categories, pattern making and alteration practices and technologies for MC and their lead times, and marker making and cutting practices and technologies for MC and their lead times.

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